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GEOLOGY AND ORE DEPOSITS

OF THE

STOCKTON AND FAIRFIELD QUADRANGLES, UTAH

BY

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GEOLOGY AND ORE DEPOSITS OF THE STOCKTON AND FAIRFIELD QUADRANGLES, UTAH

By JAMES GILLULY

ABSTRACT

The Stockton and Fairfield quadrangles lie in west-central Utah and embrace the southern portion of the Oquirrh Mountains, one of the most easterly ranges of the Basin and Range province. The mass of the Oquirrh Range is composed of sedimentary rocks, chiefly of Paleozoic age. The Cambrian system is represented by Lower Cambrian quartzite and shale, Middle Cambrian shale, limestone, and dolomite, and Upper Cambrian dolomite, aggregating about 2,500 feet in thickness and apparently conformable throughout. The Upper Cambrian is unconformably overlain by Middle (?) Devonian dolomite about 185 feet thick. Unconformably overlying the Devonian dolomite, in which karst topography had been developed on a small scale, are Mississippian beds including 450 feet of Madison limestone (lower Mississippian) and nearly 5,000 feet of limestone, with some shale and sandstone, equivalent in age to the Brazer limestone (upper Mississippian) of northeastern Utah and Idaho. A phosphatic shale at the base of this group of upper Mississippian age is noteworthy. Overlying the limestone are Mississippian shale and quartzite, immediately followed by similar rocks of Pennsylvanian age. This transition unit is about 1,100 feet thick and probably includes a minor unconformity. It is succeeded by fully 15,000 feet, perhaps 20,000 feet, of interbedded quartzite and limestone of Pennsylvanian age. There is no record of possible Permian or Mesozoic sedimentation.

At the end of the Cretaceous period or early in the Tertiary the region was compressed and the strata folded along axes which toward the south of the range trend in a north-northwest direction but toward the north edge of the quadrangles curve gradually into northwesterly and even westerly trends. These folds are all asymmetric, and some are overturned toward the northeast, but all are open and nowhere closely appressed.

Subsequent to the folding, which was accompanied by minor faulting, volcanic activity began, and considerable thicknesses of latitic breccias and tuffs were deposited, burying a topography of considerable relief. After these pyroclastic rocks (in which a few thin flows are interbedded) were laid down flow rocks predominated among the volcanic products, and a total thickness of more than 3,000 feet of extrusives accumulated. In this volcanic area there were at least two volcanic vents, one of which, Step Mountain, is marked by a breccia-filled plug surrounded by a fine example of a ring dike.

The monzonitic magma, whose ejected representatives form the volcanic series, rose locally to and into the base of its own ejecta, as in Tickville Gulch, where a diorite plug is intrusive into a latite flow. Elsewhere the monzonitic rocks, which range in composition from granodiorite to quartz diorite and diorite, probably failed to reach the prevolcanic surface. The intrusive rocks appear in small stocks, dikes, and sills which trend in an irregular belt southwestward from Butterfield Canyon to Soldier Creek and thence southward in less quantity almost to Mercur. They were accompanied by rhyolite dikes and plugs, which intruded both the volcanic rocks of the Traverse Mountains and the Paleozoic sediments. A few bodies of lamprophyre and nephelite basalt also occur, the latter both in sills and a flow.

The monzonitic intrusive rocks show some evidence of forcible injection in the deformation of the inclosing rocks. Two large normal faults in Ophir Canyon, whose combined displacement amounts to nearly 3,000 feet, are thought to owe their origin to igneous forces. Typical Basin Range faulting is prominent along the west front of the range. Contact metamorphism has been notable in the sediments surrounding the larger monzonitic masses. Marbleization, dolomitization of some limestone, and propylitization of igneous rocks have all occurred on a small scale, silicification with the production of jasperoid is widespread, and large amounts of "contact" silicates such as wollastonite, epidote, garnet, and adularia have been produced. The formation of sulphides has accompanied both the jasperoid and the silicate varieties of metamorphism, and the economically important deposits are due to this phase of the igneous metamorphism.

Ore was discovered in this area in 1864, and mining has continued on a greater or less scale to the present time. The production from the beginning of mining to the end of 1927 from all the mines of the quadrangles was probably about $49,000,000, of which over $19,000,000 was derived from the gold and gold-mercury deposits of Mercur, where work was stopped in 1913, over $20,000,000 from Ophir, and the remainder from the Rush Valley district, near Stockton. The Ophir and Rush Valley districts produce chiefly lead, silver, and zinc.

The ores occur chiefly as bedded replacement deposits and veins. Gold and mercury occur in and associated with jasperoid at Mercur, and silver and silver-lead with jasperoid near Mercur and on Lion Hill. Lead-silver-zinc-copper deposits, chiefly of bedded replacement type, occur in hornfels at Ophir and are associated with metamorphic lime-silicate rock in Dry Canyon and at Stockton. Supergene enrichment has been slight.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Stockton and Fairfield quadrangles embrace the area bounded by meridians 112° and 112° 30′ and parallels 40° 15′ and 40° 30′ and include a little more of the Oquirrh Mountains than the southern half. This area lies about 20 miles southwest of Salt Lake City, its north boundary passing 2 or 3 miles south of Bingham and Tooele, and includes portions of Tooele, Utah, and Salt Lake Counties. (See fig. 1.) The

Camp Floyd, Ophir, and Rush Valley mining districts, which include the mines of Mercur and Sunshine (inactive since 1913), Ophir, Dry Canyon, and Stockton, lie within the area, and the great mines of Bingham Canyon are just outside its northern limits.

The main line of the Los Angeles & Salt Lake Railroad passes through the Stockton quadrangle, with stations at Bauer, Stockton, St. John, and Ajax. The St. John & Ophir Railroad, owned by the Ophir Hill Consolidated Mining Co., connects the Ophir mines with this railroad at St. John station. A branch line of the Los Angeles & Salt Lake Railroad, connecting Lehi Junction with the Tintic disrict, traverses the southeastern portion of the Fairfield quadrangle, with a station near Fairfield, where the junction was formerly made with the Salt Lake & Mercur Railroad to the Mercur mining district. The line to this camp was dismantled in 1914, one year after the camp was abandoned.

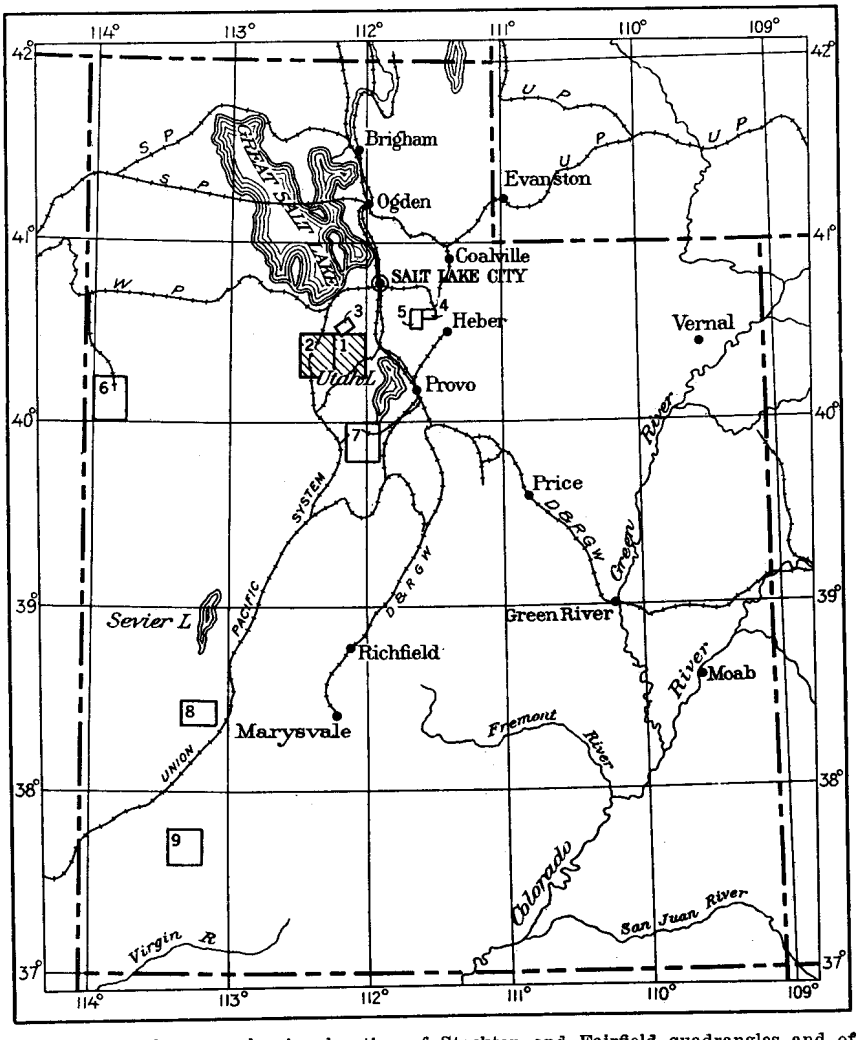


FIGURE 1.—Index map showing location of Stockton and Fairfield quadrangles and of other metalliferous districts of Utah described in detailed reports of the United States Geological Survey. 1, Fairfield; 2, Stockton; 3, Bingham; 4, Park City; 5, Cottonwood; 6, Gold Hill; 7, Tintic; 8, Frisco; 9, Iron Springs

PHYSICAL FEATURES

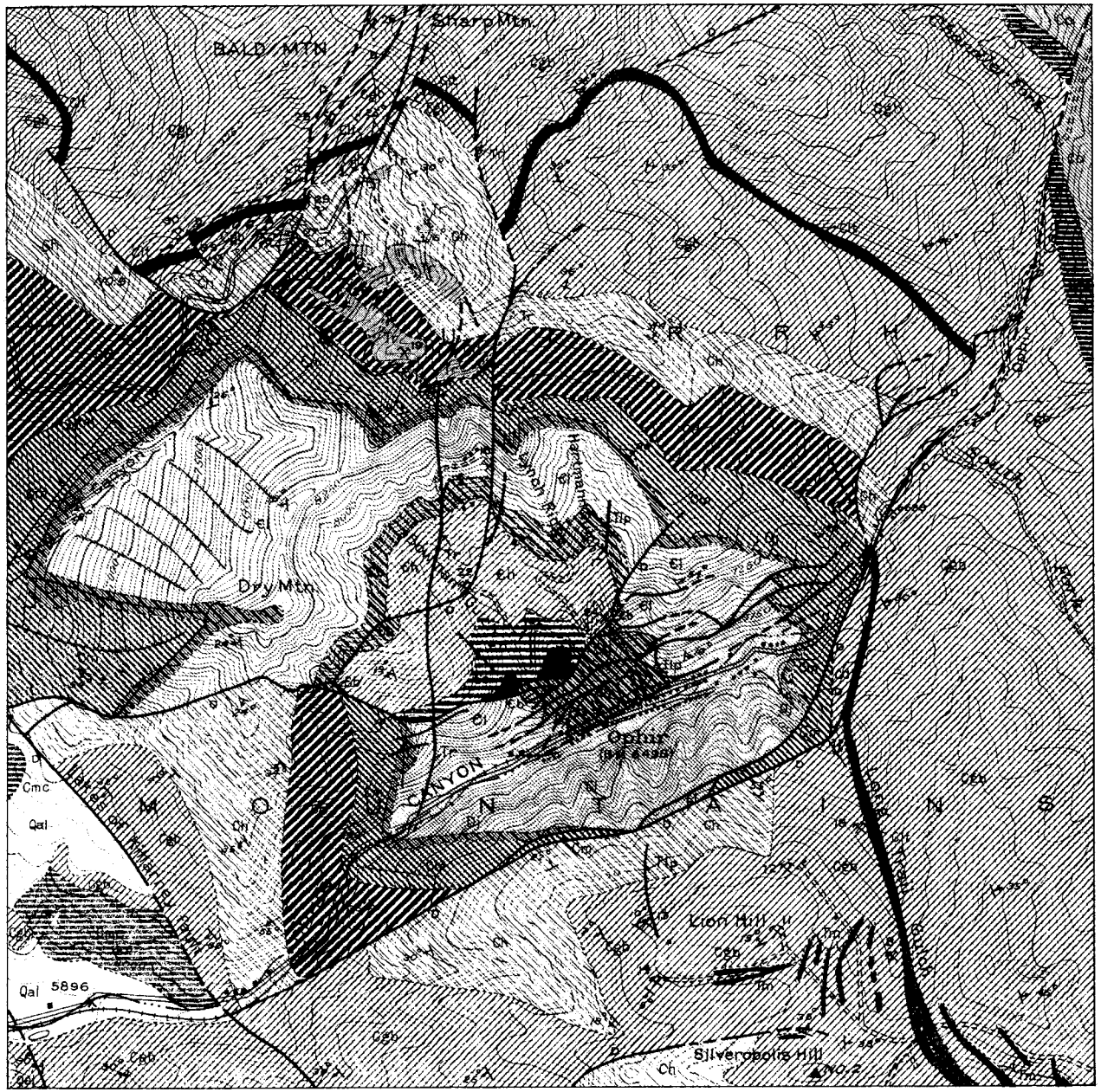
Toward the northern part of the Basin and Range province[1] its eastern limit is placed at the western base of the great Wasatch Range. Next to the west, and separated from the Wasatch only by the valley of the Jordan River, is the Oquirrh Range, which is itself less than 30 miles long but is a link in a roughly linear uplift that is continued, with only narrow interrupting lowlands, far to the south in the East Tintic and Canyon Ranges and to the north in Antelope Island, in Great Salt Lake.

Northwest of the Oquirrh Mountains lies Tooele Valley, northeast is Salt Lake Valley, and the deep depression to which both are tributary is occupied by Great Salt Lake, whose waves wash the base of the northern spurs of the range. South of Tooele Valley and separated from it by South Mountain, which forms a comparatively low transverse divide, Rush Valley forms a typical Basin Range depression between the Oquirrh and East Tintic Mountains on the east and the Stansbury, Onaqui, and West Tintic Mountains on the west. Its lowest portion, at the extreme north end, is occupied by Rush Lake, a fresh-water body, which fluctuates widely in area with the changing seasons.

East from the Oquirrh Mountains a lower spur, the Traverse Mountains, extends far out toward the Wasatch Range and divides Salt Lake Valley on the north from Cedar and Utah Valleys on the south. The constricted depression between the Traverse and Wasatch Mountains is occupied by the Jordan River, which drains the waters of Utah Lake northward toward Great Salt Lake. The undrained basin of Cedar Valley lies south of the Traverse Mountains and east of the Oquirrh Mountains and is separated from Utah Lake farther east by a narrow range, the Lake Mountains. On the south Cedar Valley is separated from Goshen Valley, a small tributary of Utah Valley, by a low divide whose existence testifies to the inadequacy of the rainfall quickly to integrate the drainage of this typical portion of the Basin and Range province.

The Oquirrh Range trends practically north and south and is from 6 to 12 miles wide. Its main divide lies a few miles east of the meridian dividing the

[1] Fenneman, N. M., and others, Physiographic divisions of the United States: Assoc. Am. Geog. Annals, vol. 6, pp. 19–98, map, 1917.



Base enlarged from U. S. G. S. map of Stockton and Fairfield quadrangles Surveyed in 1915 and 1916

0 1 Mile

Contour interval 50 feet
Datum is mean sea level

Geology by James Gilluly assisted by H. G. Mitchell, W. D. Mark, and M. J. Buerger Surveyed in 1926 and 1927.

EXPLANATION

SEDIMENTARY ROCKS

- *Pleistocene and Recent* — QUATERNARY
  - Qal — Alluvium
- UNCONFORMITY
- *Pennsylvanian* — CARBONIFEROUS
  - Cq — Oquirrh formation
  - Cm — Manning Canyon shale
- *Upper Mississippian*
  - Cgb — "Great Blue" limestone (*with Long Trail shale member, Clt, about 500 feet above the base*)
  - Ch — Humbug formation
  - Cd — Deseret limestone
- *Lower Mississipp.*
  - Cm — Madison limestone
- UNCONFORMITY
- *Middle(?) Devonian* — DEVONIAN
  - Dj — Jefferson (?) dolomite
- UNCONFORMITY
- *Upper Cambrian* — CAMBRIAN
  - €l — Lynch dolomite
- *Middle Cambrian*
  - €b — Bowman limestone
  - €h — Hartmann limestone
  - €o — Ophir formation
- *Lower Cambrian*
  - Tintic quartzite

IGNEOUS ROCKS (*Intrusive*)

- *Eocene (?)* — TERTIARY
  - Tlp — Lamprophyre (*kersantite*)
  - Tr — Rhyolite (*including Eagle Hill rhyolite, Shaggy Peak rhyolite, and Tickville rhyolite*)
  - Tm — Monzonite, monzonite porphyry, and related rocks (*including "Birdseye" porphyry*)

- D — Fault (D, *downthrown side*)
- Fault (*Location approximate*)
- 50° — Strike and dip
- Mine (*See list of mines on areal geologic map*)
- Prospect
- U. S. mineral monument

DETAILED GEOLOGIC MAP OF OPHIR AND DRY CANYONS, OQUIRRH RANGE, UTAH

Stockton and Fairfield quadrangles. Altitudes in the two quadrangles range from less than 5,000 feet in Tooele, Rush, Cedar, and Salt Lake Valleys to 10,572 feet on Lowe Peak and to 10,626 feet on the unnamed peak about a mile north of Lewiston Peak, as shown on the Fairfield topographic map. This unnamed peak was called Lewiston Peak on the topographic map of the Fortieth Parallel Survey.[2]

The mountains are rather rugged, especially near the border of the mass, though toward the south end of the range they present more rounded slopes and less precipitous canyons. Similar subdued topography is found at altitudes above 8,000 feet over a large part of the range, and it is evident that the rugged character of the parts near the intermontane depressions and the major drainage courses of the mountain mass itself is due to rejuvenation of erosion in an area formerly less sharply dissected.

Great alluvial deposits slope away from the mountain mass into the adjacent basins, there to coalesce with similar fans from the other bordering ranges. These alluvial deposits meet at very gentle slopes but rise at increasing gradients toward the mountains. The lowest parts of all these depressions were formerly occupied by the waters of the great Lake Bonneville,[3] and many of the shore features of that water body are clearly recognizable. The most marked of these features is doubtless the Stockton Bar, which extends across the valley between South Mountain and the Oquirrh Mountains just north of Stockton; but many remnants of the old beach line are clearly recognizable for long distances in both Rush and Cedar Valleys.

The general topography of the area is fairly well illustrated in the accompanying Plates 1, 2, and 3.

The drainage of the mountain mass is effected by many small canyons and a few large ones. The principal drainage courses on the west flank of the range within the area covered by this report are, from south to north, Sunshine, Mitchell, Mercur, Silverado, Ophir, Dry, Soldier, Settlement, and Middle Canyons. On the east side, Manning, Pole, West, Rose, and Butterfield Canyons are the dominant ones. Of these, only Ophir, Soldier, Settlement, Middle, West, Rose, and Butterfield Canyons carry perennial streams, and these are all very small, though of vital importance to the people of the region. Ophir and Settlement Canyons carry enough water to operate small hydroelectric plants. The drainage tunnel of the Honerine mine is a significant factor in irrigation, supplying water to 360 acres of excellent orchard and farm land. Hickman Creek and Clover Creek rise in the Stansbury Mountains, west of Rush Valley, and supply water for irrigating several farms in the valley.

[2] U. S. Geol. Expl. 40th Par., Atlas sheet III, 1877.

[3] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.

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CLIMATE AND VEGETATION

The climate of the Stockton-Fairfield area, in common with that of the remainder of the Great Basin, is arid, but the precipitation varies widely with the altitude. The only weather data for points within the quadrangles are some partial records from St. John,[4] according to which the annual precipitation may be as low as 6.43 inches. This is probably a minimum for the area. The maximum, which would be on the higher summits of the range, may approach or even slightly exceed 20 inches. St. John has a temperature range from −36° to 110° F. It is probable that this maximum is not greatly exceeded anywhere in the Stockton-Fairfield area, but on the higher peaks the minimum temperature may be somewhat lower than this.

The vegetation of the area varies notably, in response to varying conditions of rainfall, temperature, and depth of ground water. The higher areas carry, especially on northward-facing slopes, good growths of Douglas fir, with considerable spruce and some piñon and yellow pine. Aspen, scrub oaks, box elders, and alders are thick in the higher canyons and gulches. Lower mountain slopes bear a considerable growth of juniper ("cedar"), piñon, and scrub oak. The cliff rose, buck brush, June berry, and several varieties of mountain mahogany grow on many of the mountain slopes, in places making nearly impenetrable patches. Brigham's tea is a plant of the mountain slopes, and the bulb cactus, prickly pear, and sagebrush are practically ubiquitous at lower altitudes. The alluvial deposits along the watercourses near the mountain front and in the lowest parts of the intermontane depressions support considerable greasewood, but on the flanks of the basins the vegetation is practically limited to sagebrush, salt sage, bulb cactus, and prickly pear, with some bunch grasses and salt grass. Grasses are rather luxuriant on the higher slopes, or would be if the area were not so overgrazed. Lupine, Mariposa lily (Sego lily), gilia, pie weed, *Balsamorhiza*, numerous varieties of aster, and many other flowering plants are widely distributed.

A great many sheep and some cattle and horses graze over the higher hills. A few farms, irrigated from the mountain streams or from springs in the valleys, complete the rather meager list of the agricultural resources of the district. Fairfield and Cedar Fort, in Cedar Valley, and Clover and St. John, in Rush Valley, are agricultural villages. Ophir, Stockton, and Bauer are primarily mining communities, though a few small farms are tributary to each of them.

[4] U. S. Weather Bureau, Climatological data, 1919–1926.

FIELD WORK

The field work upon which this report is based began in 1925, when a reconnaissance preliminary to prospective detailed work was carried on by Sidney Paige. Mr. Paige resigned from the Geological Survey before the field season of 1926, when the work devolved upon the present writer.

With Mr. Paige's preliminary results in hand, detailed work was carried on by the writer from June 25 to October 10, 1926, and from May 1 to October 1, 1927, a total period of 8½ months. During the season of 1926 M. J. Buerger served as assistant, and in 1927 Gordon New, Leland Capener, Harold G. Mitchell, and William D. Mark assisted at different times.

The geologic map was made by means of plane table and open-sight alidade, upon a topographic base photographed to a scale of 1:31,250. The sole vertical control used was the contoured base map; accordingly stratigraphic thicknesses computed from the outcrop maps are not reliable within a limit of plus or minus two contour intervals, or 100 feet. All stratigraphic sections of less than 1,000 feet were measured by clinometer, and thicker sections were measured directly from the topographic base, details being filled in by clinometer and tape surveys. Accurate transit and tape surveys across the outcrops of the pre-Carboniferous rocks in Ophir Canyon were available through the courtesy of the Ophir Hill Consolidated Mining Co., and sections of these formations were tied to these surveys.

ACKNOWLEDGMENTS

G. F. Loughlin, geologist in charge of the section of metalliferous deposits, supervised the work throughout and visited the field twice during the progress of the work. Hearty acknowledgement is made for his numerous valuable suggestions both in the field and in the office. Adolph Knopf, then a member of the section of metalliferous deposits, spent a week visiting the writer in the field during the season of 1926 and offered many useful ideas from his wide experience in mining geology. To Sidney Paige the writer is also indebted, for his reconnaissance work was of great usefulness in giving the general setting essential to detailed geologic work, and numerous hints left in his field notes were of the utmost value. Edwin Kirk and G. H. Girty, of the United States Geological Survey, visited the writer in the field and assisted in making fossil collections and in stratigraphic work based on them. To them and to Dr. C. E. Resser, of the Smithsonian Institution, is due the credit for all fossil identifications herein incorporated. H. G. Mitchell and W. D. Mark furnished exceptionally energetic and intelligent assistance during their connection with the work.

To the numerous mining men of the region the writer is especially indebted for unfailing courtesy and cooperation. Special thanks are due to H. M. Hartmann and E. S. Bowman, of the Ophir Hill Consolidated Mining Co.; E. H. Snyder, S. E. Craig, and W. A. Young, of the Combined Metals Reduction Co.; M. C. Godbe, A. J. May, and H. G. Mitchell, of the Ophir Mono Coalition; D. W. Lynch and George St. Clair, of Ophir; Frank Dederich, of Stockton; and R. T. Walker and J. Fewson Smith, of the U. S. Smelting, Refining & Mining Co., of Salt Lake City. Much of the map of the Honerine mine is a direct copy of the work of W. A. Young, with only very minor emendations.

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GENERAL GEOLOGY

PRINCIPAL FEATURES

The Oquirrh Mountains are composed of Paleozoic sedimentary rocks and Tertiary igneous and sedimentary rocks. The bordering depressions are occupied by Quaternary alluvium and lacustrine deposits. The Paleozoic rocks include representatives of the Cambrian, Devonian, and Carboniferous systems. Of these, the Cambrian is composed of 1,800 feet of limestone, dolomite, shale, and quartzite; the Devonian, 185 feet thick, is almost wholly dolomite; and the Carboniferous, over 20,000 feet thick, is dominantly limestone and quartzite but includes subordinate amounts of shale and dolomite. The Tertiary rocks include, in addition to a negligible amount of conglomerate, monzonite porphyry, rhyolite, and latite intrusives and latite and rhyolite effusives.

Detailed regional correlations of these rocks is not yet possible because of the lack of information about many of the individually isolated ranges of western Utah. General stratigraphic similarity seems to be shown in the East Tintic and Canyon Ranges [5] and in the Wasatch Range,[6] and an attempt is made to extend such correlations as seem at present warranted.

The geologic structure of the Oquirrh Mountains is similar to that of many other ranges in the Basin and Range province. The strata have been thrown into open folds and later cut at a narrow angle by normal faults, to the displacement along which is due the present existence of the mountains. In the southern part of the range two large asymmetric anticlines, the Ophir anticline and the Long Ridge-Middle Canyon anticline, which are separated by the Pole Canyon-Selkirk Canyon syncline, are the most prominent folds. The southern continuation of the Bingham syncline borders the Long Ridge-Middle Canyon anticline on the east and extends farther south in the Lake Mountains, just outside this area, where it is the dominant structural feature.

The principal normal faults of the part of the range discussed in the present report border the mountains on the west in an en échelon series running about N. 30° W. from the area south of Mercur Canyon to the north edge of the Stockton quadrangle. Along most of this distance the faults are clearly indicated by stratigraphic displacement, distinct brecciation, and gouge, as well as notable topographic discordance on the two sides. The fact that the evidence for the normal faulting is stratigraphic and structural as well as physiographic is of added interest in view of the objections repeatedly made against the validity of the argument for " Basin Range structure " from physiography alone.

Other major faults occur in Ophir Canyon, where the dominant trends are east-west, and in Dry Canyon, where the somewhat complex faults trend mainly north, but neither of these groups of faults belong to the Basin Range system. Minor faults are present elsewhere almost throughout the quadrangles, but they are of slight importance structually as compared to the folds, although of prime economic importance.

SEDIMENTARY ROCKS

GENERAL SECTION

The sedimentary rocks exposed within the Stockton and Fairfield quadrangles have a total thickness of at least 21,000 feet, or about 4 miles. They include Cambrian, Devonian, Mississippian, Pennsylvanian, Tertiary, and Quaternary strata. Unconformities occur below the Devonian, below the Mississippian, possibly below the Pennsylvanian, below the Tertiary, and below the Quaternary rocks.

The stratigraphy of the Ophir district has been previously discussed by Wichman [7] and Olmstead,[8] who made commendable efforts to correlate the rocks with the section established at Tintic by Loughlin.[9] In this work they were severely handicapped by the lack of paleontologic assistance and were forced to depend entirely upon lithologic resemblances between the two areas. Paleontologic information has revealed remarkable differences in the stratigraphy of the two areas, so that the writer has felt impelled to apply new names to several units rather than to extend the Tintic nomenclature to this area. As a result it has

[5] Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, p. 21, 1919; A reconnaissance in the Canyon Range, west-central Utah: U. S. Geol. Survey Prof. Paper 90, pp. 53–58, 1914.

[6] Calkins, F. C., in Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 233–239, 1920.

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been necessary to differ with Olmstead and Wichman on several points, as well as with some suggestions offered by Loughlin in the Tintic report.

The stratigraphy of the area, as presented in detail in succeeding pages, is summarized in the following table:

Sedimentary rocks of the Stockton and Fairfield quadrangles, Utah

Age	Formation	Thickness (feet)	Lithology and remarks
Quaternary (Recent and Pleistocene).	Alluvial and lacustrine deposits, including Lake Bonneville beds (of Wisconsin and probably pre-Wisconsin age).	1,000+	Unconsolidated or only partly consolidated gravel, sand, and silt, overlain in the lower areas by lake silt and gravel beaches of Lake Bonneville. Some glacial fill of probable Wisconsin age in the high mountains. Some fanglomerate and stream gravel of post-Lake Bonneville age.
Unconformity			
Tertiary (Miocene or Oligocene).		200+	Fine conglomerate and coarse grit, unfossiliferous.
Unconformity			
Pennsylvanian.	Oquirrh formation.	15,000+	Interbedded lenticular quartzite and limestone, becoming more quartzitic toward the top. With very subordinate thin beds of shale and dolomite. Top not exposed in this area.
Unconformity?	Manning Canyon shale.	1,140±	Dominantly shale with some thin beds of limestone and, in the lower half, 2 fairly persistent quartzite beds. The portion above the upper quartzite is Pennsylvanian; the portion below it, upper Mississippian.
Upper Mississippian.	"Great Blue" limestone.	3,600	Light-blue limestone, with thin partings of reddish-weathering shale and with an 85-foot bed of black carbonaceous shale, the Long Trail shale member, about 500 feet above the base.
	Humbug formation.	650	Interbedded limestone and lenticular sandstone and quartzite in beds as much as 100 feet thick but ordinarily from 2 to 10 feet thick.
	Deseret limestone.	650	Blue-gray cherty limestone in beds averaging about 2 feet thick, with a 6 to 8 foot bed of phosphatic shale at the base.
Lower Mississippian.	Madison limestone.	460	Highly fossiliferous blue-gray limestone, rather thin bedded at the base, more massive and cherty toward the top.
Unconformity			
Middle (?) Devonian.	Jefferson (?) dolomite.	185	Coarsely crystalline gray dolomite, weathering dark gray; one massive bed containing conspicuous white calcite fossil casts.
Unconformity			
Upper Cambrian.	Lynch dolomite.	825–1,000	Thick-bedded light-gray dolomite, with some dark-gray dolomite spangled with short white rods in the lower part and with a few limestone beds, especially in the lower half.
(?)			
Middle Cambrian.	Bowman limestone.	280	Mottled shaly limestones, intraformational conglomerate, and oolitic limestone, with a shaly member about 35 feet thick at the base.
	Hartmann limestone.	650	Gray mottled limestone in thin beds with shaly partings some oolite toward the top.
	Ophir formation.	320	Micaceous shales, sandy toward the base, becoming less so upward and containing several beds of mottled shaly limestone.
Lower Cambrian.	Tintic quartzite.	300+	Thick-bedded cross-bedded white quartzite weathering with a rusty surface. Becomes shaly toward the top and grades into the overlying Ophir formation.

CAMBRIAN SYSTEM

LOWER CAMBRIAN SERIES

TINTIC QUARTZITE

Distribution and topographic expression.—The oldest formation exposed within the Stockton and Fairfield quadrangles is the Tintic quartzite. It crops out in only two small areas northwest of the town of Ophir, in the gulches on both sides of the spur in which is situated the portal of the old Ophir Hill Consolidated mine. In these gulches the quartzite stands in almost vertical cliffs, above which are the more gentle slopes of the Ophir formation.

Stratigraphy.—The lowest exposures of the Tintic quartzite are cut by the Canyon fault, on the south side of which the rocks have been relatively depressed so that the stratigraphic base of the formation is concealed.

The formation is almost wholly quartzite, white on fresh fracture, but with a rusty weathered surface. Its individual beds range in thickness from perhaps half an inch to about 6 feet; the average bed is about 1 foot thick. Thin argillaceous layers which are now somewhat schistose occur as partings and increase in both number and thickness toward the top, where, by their final dominance over the quartzite, the transition to the sandy shale of the Ophir formation is effected.

The beds are very irregular. Cross-bedding is prominent in all the quartzite beds. No constancy of direction of cross-bedding is apparent, complete reversal of direction being seen in a number of adjoining beds. Numerous joints and small faults oriented in many directions are visible in the cliffs, and along many of these fissures secondary silica has been deposited, making a network of quartz veins. None of the small faults can be traced beyond the quartzite outcrop, the displacements being taken up in the overlying Ophir formation by folding.

In hand specimens the rock is seen to consist almost entirely of subrounded to well-rounded quartz grains, poorly sorted and of very irregular sizes, ranging from perhaps 0.1 millimeter to 1 centimeter in diameter, though this maximum is exceptional. The rock is very thoroughly cemented, except for a few small cavities in which the grains show only slight enlargement with silica and are stained by limonite, which produces a pock-marked effect. Except in the very subordinate schistose layers, bedding laminations are practically invisible in the hand specimen.

The microscope shows the medium-grained quartzite to consist of fairly well-rounded quartz grains, most of which carry numerous minute inclusions of some highly refracting mineral, possibly rutile. The original outlines of the grains are faintly marked by brownish-iron stains, beyond which secondary enlargement has extended till the grains mutually interfere, producing a mosaic pattern when seen with crossed nicols. Some muscovite and chlorite have been developed. At a period subsequent to cementation the rock was sheared, and the brecciated silica along the shear planes has recrystallized into linear series of unoriented fine grains.

Coarser-grained specimens show less grain enlargement and apparently a greater development of muscovite than the medium-grained rock. In some of them the muscovite plates are visible to the naked eye, a feature which is also shown by the fine-grained quartzite that grades into the shale of the overlying Ophir formation. The finer-grained specimens examined also carry conspicuous quantities of angular grains of microcline, a mineral only sparsely represented in the coarser-grained specimens.

The interpretation that the Tintic quartzite grades into the Ophir formation is decidedly at variance with that advanced by Wichman,[10] who believed that there was a surface of marked erosional unconformity with a relief of at least 300 feet between the Tintic quartzite and the Ophir formation. According to Wichman's interpretation, the narrowing of the exposed part of the Ophir formation is due to this unconformity, but the writer believes that this narrowing is entirely explained by structural features of much later origin—the Ophir anticline and the Canyon fault, through the conjunction of which the crescentic outcrop of the Ophir formation has developed. The lithology of the beds just above and below the contact strongly supports the view of the conformity of the two formations. Olmstead[11] differed with his coworker, Wichman, on this point, for he states that the two formations are conformable. As the transition zone between continuous quartzite and continuous shale is 30 to 40 feet thick, the selection of a boundary between the two formations is quite arbitrary. In surface mapping the boundary was drawn at the base of the lowest thick bed of sandy shale, which, in the gulch below the old Wild Delirium mine, is 5 feet thick. This choice of boundary limits the exposed Tintic quartzite to a thickness of 294 feet and throws perhaps most of the transition zone into the Ophir formation. Comparison of the section as exposed on the surface with that penetrated on the tunnel level of the old Ophir Hill Consolidated mine suggests that for underground work the boundary would be better placed some 30 feet higher, for underground the affinities of most of the transition beds appear to lie with the quartzite rather than with the shale. However, the underground exposures are so few that the location of the boundary is believed to be better based upon the surface information.

Correlation.—Although none of the basal Paleozoic quartzite formations in Utah contain fossils, it seems fairly certain that the quartzite at Ophir is to be correlated with the Tintic quartzite of the Tintic Range, 30 miles to the south, and with the Cambrian quartzites of the Wasatch and House Ranges, as all these quartzites lie conformably beneath a shale formation which carries fossils that have been referred to Lower and Middle Cambrian time.

[10] Wichman, F. M., The Ophir mining district, Utah: Eng. and Min. Jour., vol. 110, pp. 561–563, 1920.

[11] Olmstead, S. G., Economic geology of the Ophir mining district, Utah: Econ. Geology, vol. 16, p. 439, 1921.

Section of Ophir formation at Ophir

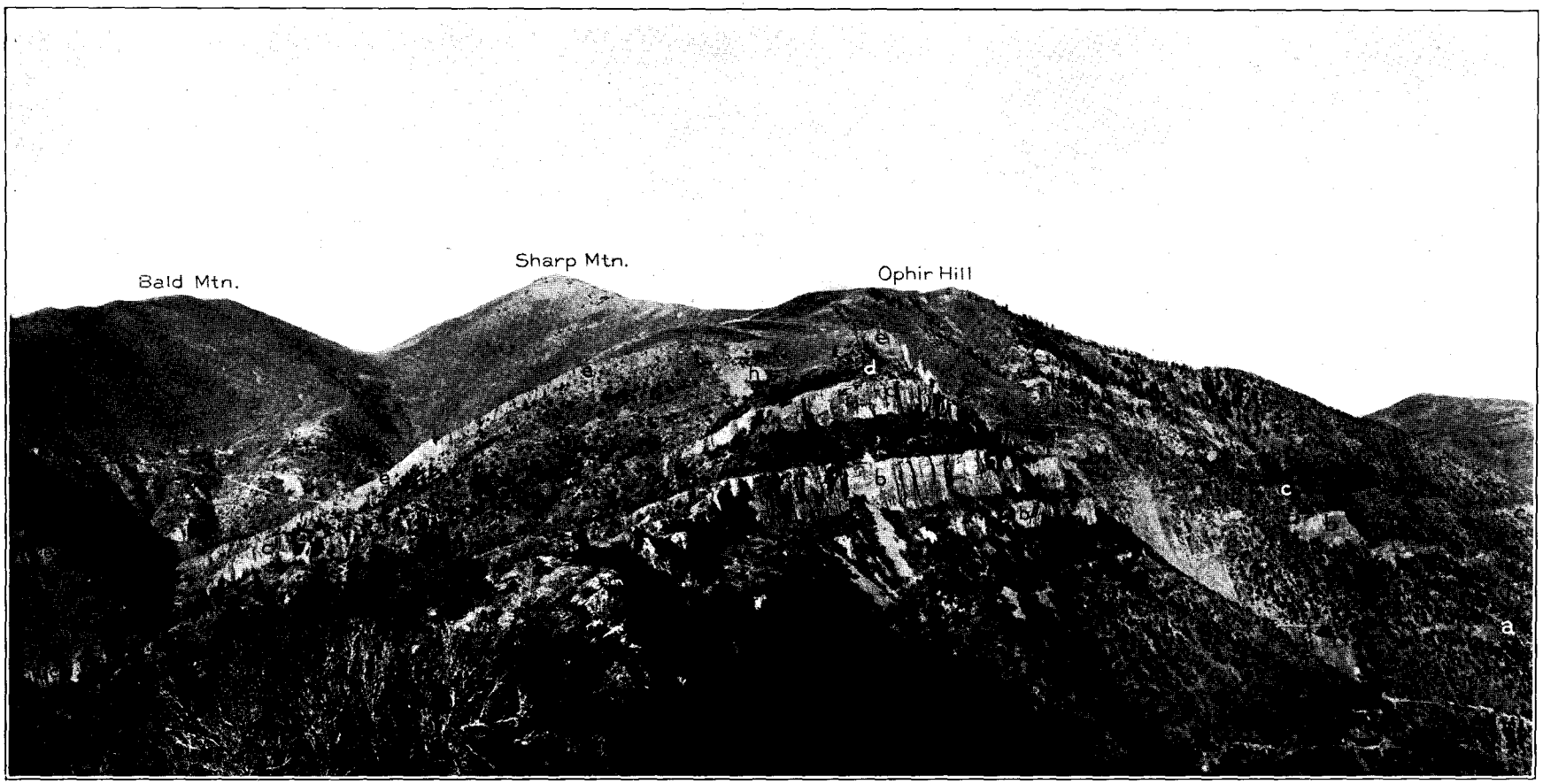
	Feet
Hartmann limestone.	
Section crossed by small fault with throw of less than 4 feet.	
Ophir formation:	
1. Interbedded limestone and shale, highly altered and bleached, containing epidote and pyrite	4
2. Dark-gray shale, mottled with brown on fresh surfaces and weathering uniformly dark brown, fine grained, not sandy, blocky and highly jointed, with no marked tendency to split along bedding surfaces	62
3. Dense blue-gray limestone, mottled by irregular bands of shale. The shale layers range from ⅛ inch to 1 inch in thickness and weather dark brown; the limestone, in layers of ⅛ inch to 2 inches, weathers dark blue-gray, giving a streaked appearance to the outcrop. These mottled beds range from 6 inches to 2 feet in thickness and are separated by wavy bedding surfaces and broken by numerous faults of small throw. This member includes part or all of the "Big vein" and "Top vein" of the Ophir Hill mine	41
4. Light-gray shale, poorly laminated, which weathers almost white except along fractures, where it is stained brown. The shale is practically free from mica, very blocky, and with very poor lamination. Some layers are decidedly limy	32
5. White-weathering shale, light gray on fresh fracture, poorly exposed, poorly bedded, with only fine particles of mica and no tendency to schistosity. The "Middle vein" of the Ophir Hill mine is probably represented in this member	26
6. Concealed, the "Blue vein" and "Copper vein" of the Ophir Hill mine are doubtless represented in this member	54
Within this member, 70 feet east of the line of the section and with exact stratigraphic location indeterminate, are the following exposures:	
Poorly bedded, iron-stained shale	4
Poorly exposed gossan; presumably represents alteration of a replaced limestone bed	17
Pyritized and somewhat silicified limestone	3
7. Thinly laminated, somewhat sandy, very light greenish-gray shale which weathers practically white with some rusty blotches. The shale is blocky, with only a small amount of mica. Grades downward into No. 8	40
8. Chiefly very light greenish-gray, white-weathering, thinly laminated blocky shale with many interbedded lenses of white quartzite. The quartzite lenses range from 1 inch to 1 foot in thickness but are everywhere subordinate to the shale. Grades downward into No. 9	12
9. Thinly laminated quartzitic shale, blocky, closely jointed, breaking into angular blocks ½ inch to 2 inches on a side	18
Ophir formation—Continued.	Feet
10. Quartzose mica schist similar to bed 12 and quartzite like the Tintic quartzite, alternating in layers from ¼ inch to 2 inches thick. The member is highly quartzitic but has a laminated aspect like a typical schist	20
11. Quartzite, very light gray, identical in appearance with Tintic quartzite, in one bed	5
12. Highly quartzose, thinly laminated greenish-gray, brown-weathering schist. The bedding surfaces are greatly slickensided, with a considerable development of mica. The chief constituent is fine-grained quartz. Individual laminae of schist range from $\frac{1}{16}$ to ¼ inch in thickness. Sporadic quartzite lenses as much as 2 inches thick are present	5½
Conformable contact.	
Tintic quartzite.	319½

The limestone beds of the Ophir formation, which are of paramount economic importance, have been thoroughly investigated in the workings of the Ophir Hill Consolidated Mining Co., whose engineer, E. S. Bowman, kindly furnished the following summary of the section as it appears in the mine workings:

	Feet
Unnamed limestone, only slightly productive	5– 8
Shale	60
"Top vein" limestone	5– 8
Parting, shaly	2
"Big vein" limestone	20–40
Shale, approximately	25
"Middle vein" limestone	10–14
Shale, approximately	25
"Copper vein" limestone	8
Parting, shaly limestone	1½– 2
"Blue vein" limestone	6
Shale	57
Quartzitic shale	44½
	299½

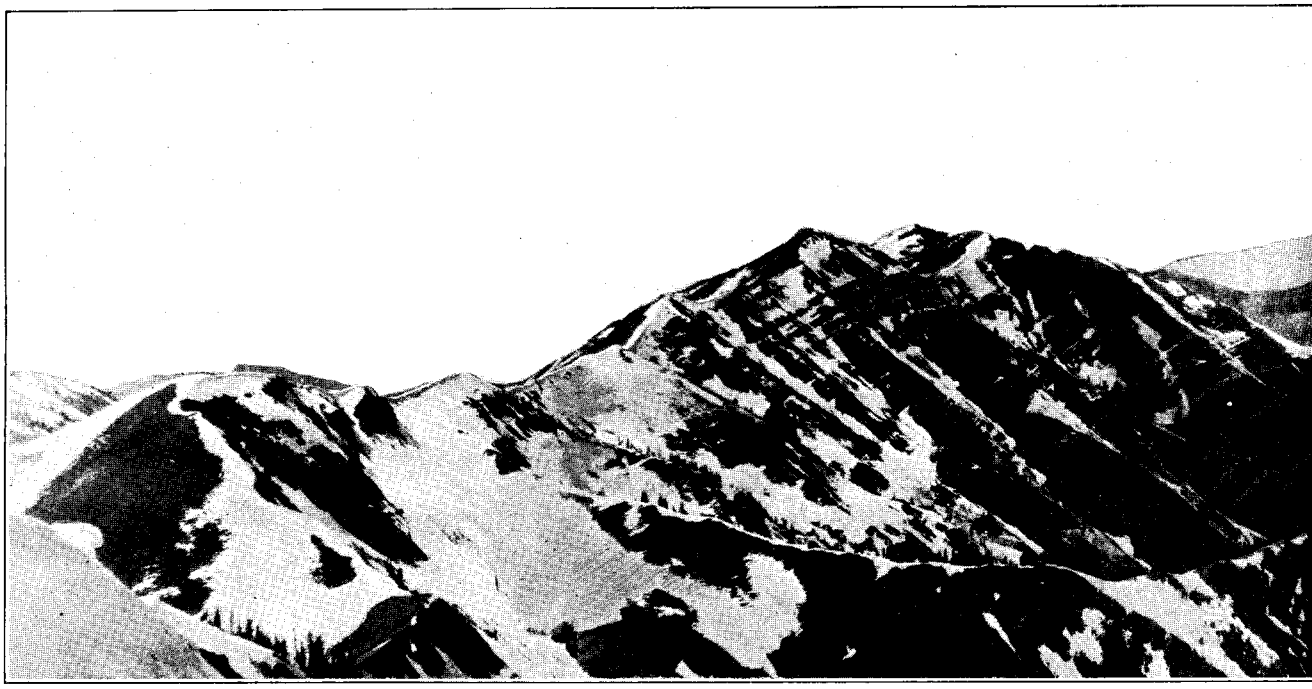
The two units at the base of this section were measured by the writer.

The limestones of the Ophir formation are, as a rule, poorly exposed on the surface, and they are so much altered in most of the mining exposures that it is difficult to get any good idea of their unaltered appearance. However, in the "7½" drift of the old Ophir Hill Consolidated mine apparently unaltered limestone of the "Copper vein," remote from any ore body, is seen. This limestone is dense, very dark gray, and very faintly mottled. The mottling seems to be due to variations in the silt content of the various layers and slightly to the carbon content. Toward the ore body the mottling is more and more striking, with the development of metamorphic minerals and oxidation or removal of the carbon content. These changes are more fully described in the section of this report dealing with metamorphism and are mentioned here merely to call attention to the fact that the banded and mottled crystalline rock ("zebra rock") which is com-



VIEW LOOKING NORTH AND NORTHEAST FROM A POINT ON THE DRY CANYON-OPHIR CANYON DIVIDE ABOUT A QUARTER OF A MILE SOUTHWEST OF MINERAL MONUMENT NO. 4

a, Hornfels ledge at base of Bowman limestone; b, Lynch dolomite; c, Jefferson (?) dolomite; d, Madison limestone; e, cherty ledge at top of Madison limestone; f, tramway station of Cliff (Buckhorn) mine; g, upper tunnel of Cliff mine; h, Chicago incline; i, Hidden Treasure incline.



A. VIEW LOOKING NORTH FROM LOWE PEAK

Main divide of the Oquirrh Range at left. Snow-covered saddle at right is on axis of Long Ridge anticline and marks head of White Pine Canyon. In ri
Canyon and Jackson Hollow.

B. LION HILL FROM NORTH SIDE OF OPHIR CANYON, SHOWING OPHIR ANTICLINE

C. LAND
CAN

The slide
slope o
high an

monly seen near the edges of the ore bodies owes its striking color banding to changes connected with ore deposition, not to its original character.

The microscope reveals a little silt but almost no constituent of importance, other than calcite, in the limestone. Much of the mica of the shales of the upper part of the formation is seen to have a haphazard arrangement, though lamination is pronounced. This lack of parallelism among the mica individuals is in distinct contrast to their parallel leaf-like arrangement in the schist in the lower part of the formation, but the possibility that the upper beds where examined may have undergone hydrothermal alteration, with the resultant development of the haphazard mica (or sericite) plates renders the textural differences of questionable significance. As nearly as can be determined, either in the field or under the microscope, the schistosity is parallel to the bedding in these lower layers. It seems probable that this parallelism resulted from differential tangential movements in the lower beds of the Ophir formation in response to the folding of the Ophir anticline. This adjustment presumably produced the proper stress conditions for growth of the mica plates, whose orientation was doubtless governed in part by the resolution of the forces of compression normal to and parallel to the bedding and perhaps in part by greater permeability of the rock in this direction. That the schistosity is hardly to be attributed to pure load metamorphism seems very probable, as stress conditions, due to load above, can not have been appreciably more rigorous in the lower than in the upper part of the formation, which likewise must have been buried under fully 20,000 feet of rock during this folding. This conception of the cause of the schistosity is supported by the slickensided condition of the lower, more schistose beds as contrasted with the upper shaly ones.

The area of outcrop of the Ophir formation is very small at Ophir, and opportunities for observation are correspondingly meager; but even so, its variations seem considerable, a characteristic of the formation elsewhere, as is pointed out by Loughlin[21] for the Tintic district. The notable variations in the thickness of the several limestone beds indicated in the section furnished by Mr. Bowman are not due entirely to variations in the thickness of minable ore, but in a considerable degree, at least, to actual local differences in the beds themselves.

The determination of the upper contact of the Ophir formation, like that of the lower, is arbitrary, though there is considerably less transitional material at the top than at the bottom. The boundary between this formation and the Hartmann limestone is drawn at the top of the highest shale bed in this part of the section. It is probable that over a wider area this boundary would prove to be of variable horizon, as the shale probably lenses in and out through a greater or less stratigraphic interval, but in the small exposure of Ophir Canyon no notable variation was seen.

Age and correlation.—Fossils from the Ophir formation, collected from schistose beds less than 50 feet above the base, were submitted to Dr. C. E. Resser, of the Smithsonian Institution, who reports as follows:

> Localities 4 and 6 contain a Middle Cambrian fauna which is characterized by *Dolichometopus productus*. Collection 5 seems to have a specimen of *Neolenus*. All of this Ophir shale group is represented in the near-by Wasatch and elsewhere, occupying a position below the middle of the Middle Cambrian.

Walcott[22] lists the following fossils from the Ophir formation at Ophir:

> About 75 feet above the quartzitic sandstones of the Cambrian:
>
> Obolus (Westonia) ella.
>
> Concretionary limestone about 100 feet above the quartzitic sandstones of the Cambrian:
>
> Micromitra sp.
> Micromitra (Paterina) labradorica utahensis.
> Obolus (Westonia) ella.
> Olenoides(?).

These are all assigned to the Middle Cambrian. However, in discussing the Cambrian of Utah, Walcott[23] stated:

> The section in the Oquirrh Range above Ophir City has a quartzite at the base with shale above it carrying *Lingulella ella, Olenellus gilberti,* and *Bathyuriscus producta,* as determined by the collections brought in by the Wheeler Survey. It is probable, however, that as in the case of the Big Cottonwood section, *Olenellus gilberti* occurs at the base of the shale, and the other two species at a higher horizon.

In this paper, as in other publications, Walcott restricted *Olenellus* to the Lower Cambrian. This restriction has been questioned by Ulrich[24] and by Burling,[25] though Burling agrees with Walcott in assigning the lower part of the Ophir formation to the Lower Cambrian. However, later study by Walcott[26] of the *Albertella* fauna (upon which Burling's question was based) failed to convince him that *Olenellus* has been yet found at any horizons stratigraphically above *Albertella.* He accordingly did not relinquish his position that the presence of *Olenellus* is alone a sufficient criterion for ascribing beds to the Lower Cambrian.

[21] Loughlin, G. F., op. cit. (Prof. Paper 107), pp. 25, 26.

[22] Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pt. 1, pp. 164–165, 261, 1912.

[23] Walcott, C. D., Correlation papers—Cambrian: U. S. Geol. Survey Bull. 81, pp. 319–320, 1891.

[24] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 619–620, 1911.

[25] Burling, L. D., Early Cambrian stratigraphy in the North American Cordillera, with discussion of *Albertella* and related faunas: Canada Geol. Survey Mus. Bull. 2, pp. 113, 128–129, 1914.

[26] Walcott, C. D., The *Albertella* fauna in British Columbia and Montana: Smithsonian Misc. Coll., vol. 67, No. 2, pp. 9–60, 1917.

On this basis, the Ophir formation is in part Lower Cambrian and in part Middle Cambrian in age. Diligent search during this survey failed to reveal any specimens of *Olenellus*, so that it is impossible to say how much is Lower and how much Middle Cambrian. The fossils ascribed to the Middle Cambrian by Doctor Resser were collected within 50 feet of the base of the formation, so that if the Lower Cambrian is present it includes less than this thickness of Ophir beds. Careful search failed to reveal any sharp lithologic change or any unconformity within this interval. The schistose material discussed above extends higher than this, so that the absence of schistosity in the topmost part of the formation and its presence toward the base can not be considered evidence of a significant difference in the age of these beds. Accordingly, either sedimentation was here continuous between Lower and Middle Cambrian time, or *Olenellus* survived into the Middle Cambrian, as was stated by Ulrich[27] to be true in the Appalachian region. The only other possible interpretation is that an unconformity really is present but escaped observation. If so it is not marked by notable erosion, angular discordance, or sharp lithologic differences, and the writer believes it exceedingly improbable that one exists.

The rocks here included in the Ophir formation were correlated with the shale just above the Cambrian quartzite of the Wasatch Range by Emmons,[28] and this correlation was accepted by Walcott.[29] Walcott correlated it further with the shale at the top of the Cambrian quartzite in the Highland Range, Nevada; with that at the top of the Prospect Mountain quartzite in the Eureka district, central Nevada; and with the lowest shale of the House Range, Utah. These correlations he later modified in some details[30] as more thorough studies were made. Burling[31] gives an excellent summary of the correlations made by Walcott up to 1908, laying great stress on the presence of the two faunal zones—the *Olenellus gilberti* zone and the *Bathyuriscus producta* zone. This summary presents the paleontologic results, which have not since been questioned. Stratigraphic and lithologic variations that were originally thought to be slight in this part of the section over wide areas in Utah, Idaho, and Nevada have since proved to be more complex,[32] so that formation names are not to be extended with as much confidence as the paleontologic correlations. Such correlations as seem justified from the evidence are indicated in Figures 2 and 3. The term Ophir formation, from the locality here described, was proposed for these beds by B. S. Butler.[33] It has been extended by Loughlin[34] to the Tintic district, and the formation has been identified by Calkins[35] in the Cottonwood district.

[27] Ulrich, E. O., op. cit., pp. 619–620.

[28] Emmons, S. F., Descriptive geology: U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 444, 1877.

[29] Walcott, C. D., Cambrian faunas of North America: U. S. Geol. Survey Bull. 30, pp. 39–40, 1886.

[30] Walcott, C. D., Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., vol. 53, No. 5, pp. 171–185, 1908.

[31] Burling, L. D., op. cit., pp. 120–125.

[32] See especially Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey Prof. Paper (in preparation). Westgate, L. G., and Knopf, Adolph, Geology of Pioche, Nev., and vicinity: Am. Inst. Min. and Met. Eng. Tech. Paper 1647, I, 1927; Geology and ore deposits of the Pioche district, Nev.: U. S. Geol. Survey Prof. Paper 171, 1932.

MIDDLE CAMBRIAN SERIES

HARTMANN LIMESTONE

Distribution and topographic expression.—Resting conformably upon the Ophir formation is the formation here named Hartmann limestone, from its excellent exposures on the west side of Hartmann Gulch (sometimes called Graveyard Gulch), just north of Ophir. It crops out in the north wall of Ophir Canyon from the large gulch that descends the southeast flank of Dry Mountain about a mile due west of Ophir, where it is cut off by a fault on the west, to Hartmann Gulch, on the east side of which it is cut off and dropped out of sight by the northeastward-trending branch of the Canyon fault. It is exposed nowhere else within these quadrangles.

In this area the formation makes a steep slope, clad rather thickly with scrub oaks and mountain mahogany.

Stratigraphy.—The boundary between the Ophir formation and the Hartmann limestone is an arbitrary one, the transition from the shale and limestone of the Ophir to the uninterrupted limestone sequence of the Hartmann being somewhat gradual. No evidence of any depositional hiatus between them was detected, and the boundary was placed at the top of the highest observed shale bed, throwing all the shales into the Ophir formation.

The Hartmann formation consists dominantly of limestone, banded with mudstone material, which is distributed in a peculiar manner so that the weathered surfaces of the limestones are irregularly mottled with light gray, buff, and brown. Some of the mudstone bands are parallel to the bedding and are connected at closely spaced intervals by streaks of the same material normal to the bedding and suggestive of filled mud cracks. Another group of strata in the formation has similar mudstone arranged in extremely sinuous, bulbous, and involved patterns, giving the impression of filled worm borings. Still another type shows rounded biscuit-shaped masses of mudstone of a pseudoconcretionary aspect, connected, at least in part, by thin streaks of the same material. Many of these struc-

[33] Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 79 et seq., 1920. The use of the term in many of the areas farther west in Utah, as advocated by Butler, is believed to be at present premature, in view of the detailed work of Westgate and Nolan, cited above.

[34] Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 25 et seq., 1919.

[35] Calkins, F. C., oral communication.

tures seem explicable as those of edgewise conglomerates or as filled worm tubes, but no adequate explanation of many of the other types occurs to the writer. The mottling is so definite, however, and so widespread in the lower Paleozoic section of much of Utah that it is of great value in stratigraphic work. The Cambrian of the Wasatch Mountains near Salt Lake City and in the Cottonwood Canyon section, the Cambrian and Ordovician of the Tintic district, and most of the early Paleozoic of the Deep Creek Range[36] are all characterized by similar mottling. Typical examples are illustrated in Plate 4. The following section is a continuation of the section of the Ophir formation given on page 10.

Section of Hartmann limestone on spur above Wild Delirium mine

	Feet
Bowman limestone; thick brown-weathering pyritized hornfels at base.	
Apparent conformity.	
Hartmann limestone:	
1. Limestone, blue mottled, crystalline to dense, containing round black spots about ⅛ inch in diameter and irregular lumpy partings of buff-weathering mudstone. Locally oolitic, carrying black oolites about ⅛ inch in diameter in a gray shaly matrix. Bedding irregular, with wavy surfaces; beds range from 2 inches to 5 feet in thickness	31
2. Limestone, dark and light gray, sandy and oolitic, in beds about 2 feet thick. Poorly exposed	21
3. Concealed; probably limestone	39
4. Oolitic limestone, like No. 2	6
5. Limestone, dark blue-gray, very irregularly mottled with mudstone, which weathers white through buff to brown. The mudstone partings are very irregular but are spaced from ½ inch to 2 inches apart and range between ⅛ and ½ inch in thickness. The banding is pronounced on general view but is not particularly noticeable in hand specimens. Bedding massive, chiefly in beds 8 to 10 feet thick	107
6. Limestone, dense, gray, and greenish-gray mudstone, weathering brown, poorly bedded. The mudstone shows slickensides and silicification. The limestone carries irregular dark-gray blebs, some of which are vermicular. The member forms a ledge and weathers light gray as a whole	3
7. Concealed; probably limestone, mottled with mudstone like No. 8	38
8. Limestone, dark blue, weathering lighter blue-gray, in beds ½ inch to 1½ inches thick separated by buff to cream weathering sandstone in layers ⅛ to ½ inch thick. Sparsely fossiliferous	102
9. Limestone, light blue-gray, fine grained, somewhat cross-bedded, banded with brown-weathering mudstone, which locally shows "contact" minerals. Forms strong, persistent ledge	6
Hartmann limestone—Continued.	Feet
10. Poorly exposed; irregularly bedded limestone	74
11. Limestone, mottled somewhat with sandstone. Average bedding 2 inches to 1 foot thick. The limestone carries numerous black vermicular marks ⅛ to ¼ inch in diameter and as much as 1½ inches long, arranged entirely without system. These markings are now composed each of a single calcite crystal	27
12. Limestone, average bed about 2 inches thick. Crystalline locally, mottled with mudstone. Occasional trilobite remains occur. Upper part poorly exposed	99
Fault crosses section, and mine developments show that 40 feet of beds are here lost to view	40
13. Limestone, dark blue-gray on fresh fracture, weathering light gray, in layers ½ to 3 inches thick, mottled with mudstone in layers ⅛ to ½ inch thick, with tendency to follow the bedding, which weather buff. Weathers into beds from 1 to 4 feet thick, broken by joints into large blocks	61
Transitional boundary.	
Ophir formation: Interbedded limestone and shale.	654

[36] Nolan, T. B., oral communication.

Microscopic examination reveals no unusual features of sedimentary origin, the banding being apparently due merely to variations in proportions of silty matter. No dolomite was detected in this formation.

The upper limit of the Hartmann limestone is taken at the base of a conspicuous thick brown-weathering hornfels ledge that crops out in a roughly semicircular arc around the exposures of the older rocks. The contact is apparently conformable and is discussed further in treating the Bowman limestone, of which this ledge is considered the basal member.

Age and correlation.—Fossils are not numerous in the Hartmann limestone, but scant faunules have been collected at several horizons within it. The collections made by the writer have been reported on as follows by Dr. C. E. Resser:

Collection F1: About 110 feet above base of Hartmann limestone, on west side of Hartmann Gulch, Ophir Canyon.

Collection F2: About 310 feet above collection F1, in Hartmann limestone.

Collections F1 and F2 are Middle Cambrian, containing well-known but largely undescribed faunas. F1 contains *Dorypyge;* F2 represents the common blue Middle Cambrian limestone as it occurs in the House Range.

Wichman[37] correlates the strata here included in the Hartmann limestone with the Teutonic and Dagmar limestones as recognized by Loughlin[38] in the Tintic mining district. In this correlation he was followed by Olmstead.[39] The writer is unwilling to attempt so close a correlation between districts so widely sepa-

[37] Wichman, F. M., The Ophir mining district, Utah: Eng. and Min. Jour., vol. 110, pp. 560–563, 1920.

[38] Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 27–28, 1919.

[39] Olmstead, S. G., Economic geology of the Ophir mining district: Econ. Geology, vol. 16, p. 440, 1921.

rated (30 miles) as Ophir and Tintic. There is little doubt, however, that the lower part of the Hartmann limestone as here described is equivalent to the lower part of the Teutonic limestone of Tintic. The very remarkable lithology of the Dagmar limestone of that district finds no counterpart in Ophir Canyon, however, and as the ages of these several formations can not be differentiated from the paleontologic evidence at hand and the original distinction of the Dagmar is based solely on its peculiar lithology, the extension of the term seems unacceptable. The writer was able to observe no really mappable division of the strata here grouped. It is true that oolites and edgewise conglomerates begin to come in toward the top, but these are not persistent features so far as observed, and no adequate basis for a division of the unit was found.

The Hartmann limestone is probably to be correlated, at least in part, with the Cambrian limestones of the Cottonwood district of the Wasatch Mountains described by Calkins,[40] but no precise correlation between these two areas seems warranted from the information at hand, as the fossils from both districts are few and not particularly good horizon markers.

BOWMAN LIMESTONE

Distribution and topographic expression.—Conformably overlying the Hartmann limestone is a series of mottled limestones and limy mudstones and shales, the latter now found as hornfels, which crop out in a rough arc in the wall of Ophir Canyon north of the town. This formation is here called the Bowman limestone, from its excellent exposures in Bowman Gulch, northwest of Ophir. The outcrop is cut off on the west by the Canyon fault in the gulch that descends southeastward from Dry Mountain, west of Ophir. From this point its outcrop extends east and northeast to the lower buildings of the Cliff mine and thence south and east to the east wall of Hartmann Gulch, where it is again cut off by the Canyon fault.

A small area on the spurs between the Canyon fault and the town of Ophir and within the town exposes mottled limestone resembling this formation and so shown on the map (pl. 12), but the upper boundary of this formation is not distinctive, and it is possible that these rocks correspond in horizon to the base of the Lynch dolomite as mapped near the Cliff mine.

Stratigraphy.—The outcrop of the basal bed of the formation is a prominent ledge almost throughout its length. Its resistance to erosion is doubtless due to its metamorphism from a limy shale to a massive hornfels. The degree of metamorphism varies decidedly from place to place and from layer to layer within the member at any given locality, so that some limestone, some argillite, and some shaly dolomite are found to make up portions of the unit. Its lithology is illustrated in Plate 5, *B*. The alteration is described in more detail in the section on metamorphism.

Above the hornfels member, which averages perhaps 35 feet in thickness, is a series of mottled shaly limestones, edgewise conglomerates, and oolite beds, the limestones practically indistinguishable from the mass of the Hartmann limestone and the conglomerates and oolitic beds finding counterparts in the upper portion of that formation. A typical example of the edgewise conglomerate is illustrated in Plate 5, *A*. Argillaceous layers, also in part altered to hornfels similar to the basal bed, recur at several horizons in the limestone but are subordinate in the formation as a whole.

The following section of the Bowman limestone represents its character where exposed on Lynch Ridge just east of the lowest tunnel of the Cliff mine:

Section of Bowman limestone on Lynch Ridge

[Strike N. 40° W.; dip 12° N.]

	Feet
Lynch dolomite: Dark blue-gray dolomite spangled with rods of white calcite.	
Conformable contact.	
Bowman limestone:	
1. Dark blue-gray limestone, streaked with irregular white crystalline calcite markings roughly parallel to the bedding, carrying sporadic nearly black oolites and numerous scattered cylindrical rods of calcite. The beds of the member range from 1 foot to 4 feet in thickness	55
2. Concealed	53
3. Poorly exposed limestone, dark bluish gray, weathering light gray, mottled with shaly material in irregular and discontinuous layers. The limestone beds range from ½ inch to 8 inches in thickness and average about 3 inches. The shaly streaks hardly exceed ⅜ inch in thickness and weather buff to brown. A few oolitic layers occur	28
4. Hornfels and magnesian argillite with subordinate limestone. Much pyrite occurs in the bed, which has a greenish-gray cast on fresh fracture but weathers to a deep brown. Forms a low ledge	8
5. Limestone like that in bed 3	8½
6. Somewhat shaly and metamorphosed limestone and dolomite with some flat rounded limestone-pebble conglomerates of the intraformational type. Some thin layers of unaltered limestone occur	14
7. Limestone like that in bed 3, with prominent dark-gray vermicular markings due to somewhat more carbonaceous material. These markings range from ⅛ to ¼ inch in diameter and are as much as 1 inch long. They seem to show no general orientation. About 30 feet above the base is a 1-foot bed of "intraformational" limestone conglomerate. (See pl. 5, *A*.) Similar beds occur 5 feet and 7 feet higher. The top 15 feet is not well exposed	70

[40] Calkins, F. C., in Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 236, 237, 1920.

Bowman limestone—Continued.	Feet
8. Argillaceous limestone and limy argillite, containing considerable pyrite. Gray to greenish gray on fresh fracture; weathers to a reddish brown. "Contact minerals such as epidote and garnet are plentiful, and the whole member is now dominantly hornfels. Interbedded are a number of layers of limestone conglomerate---	41
	277½

The upper boundary of the Bowman limestone is difficult to draw. The normal limestones of the upper strata pass gradually into a series of beds that vary along the strike between limestone and dolomite. In tracing a given bed it was observed to vary from limestone to dolomite and back to limestone within 20 feet. In several sections measured within 200 yards of one another the position of the lowest dolomite bed varied over 80 feet stratigraphically, yet this was not a feature related to any apparent mineralized fissures, nor could the relation be ascribed to faulting or unconformity. Similar difficulty in fixing the lower boundary of the Lynch dolomite was experienced by the local mining geologists and engineers, and it is believed by them as well as the writer that the variation in the position of the base is a sedimentary feature, not connected with unconformity or local structure. No boundary that would be everywhere satisfactory could be established in the field. It is believed that the section measured on the backbone of Lynch Ridge east of the Cliff mine probably carries dolomite as low stratigraphically as any other section in the district, and the boundary between the Bowman limestone and the Lynch dolomite is here arbitrarily drawn at the base of the lowest dolomite outcrop on that ridge.

The boundary as mapped shows only the approximate limit between limestone and dolomite. To show the actual limit would be rather confusing than otherwise, as it passes up and down through a stratigraphic interval of well over 100 feet and its delineation would introduce apparent structural complexities where none exist. Accordingly, in a number of places rocks mapped as part of the Lynch dolomite are quite as pure limestones as any in the Hartmann or Bowman, but such limestones are nowhere very thick, nor is there any confusion as to their true position in the section save possibly in the locality referred to above, on the spurs south of the Canyon fault and between it and the valley of Ophir Creek in the town of Ophir.

In the new shaft of the Ophir Hill Consolidated Mining Co., on the south side of Ophir Canyon, in which, as the beds are there practically horizontal, nearly their true thickness is revealed, the lowest dolomite was penetrated at 150 feet below the adit, and the basal shale of the Bowman formation was bottomed at 510 feet. This interval, 360 feet, is over 80 feet greater than the one arrived at by the surface measurements given above and seems clearly to point to transition of dolomite to limestone at the base of the Lynch dolomite in the interval between these localities, such as was verified near the type section of the Bowman limestone just discussed.

Age and correlation.—The rocks here included in the Bowman limestone have been referred to the Herkimer limestone of the Tintic district by Wichman.[41] Olmstead[42] also included them in the Herkimer limestone, but his formation was apparently somewhat more inclusive than Wichman's or the present writer's, for he gives a total thickness of 405 feet for the Herkimer, compared with 268 feet as given by Wichman and 277 feet for the Bowman limestone as given in this report. This discrepancy is doubtless due, at least in part, to the variable position of the boundary between limestone and dolomite above referred to.

As is evident from Loughlin's[43] description of the Herkimer limestone in its type locality, the Tintic district, it greatly resembles the Teutonic limestone of that district—so closely, in fact, that were it not for the intervening Dagmar limestone, of unique lithology, the two would not have been differentiated. The writer considers it highly probable that the rocks of the Bowman limestone as here defined are at least in part equivalent to a portion of the type Herkimer; nevertheless he feels that the use of that name in the area here described, predicated as it would be on the recognition of a subjacent unit equivalent to the Dagmar and an overlying one equivalent to the Bluebird dolomite, is not warranted. Useless multiplication of stratigraphic names is certainly to be deplored, but the writer feels that too widespread correlation of stratigraphic units that are primarily established for local reasons on a merely lithologic basis is equally to be avoided without rather conclusive evidence of their equivalence.

A few poor collections of fossils were made from this formation, upon which Doctor Resser reports as follows:

> Collection F3: From limestone about 120 feet above the base of the Bowman formation on Lynch Ridge.
> Collection F14: From limestone about 240 feet above the base of the Bowman formation on Lynch Ridge.

Collection F3 is Middle Cambrian, containing well known but largely undescribed faunas. It contains *Dorypyge*. Collection F14 contains a strange trilobite, and guessing at its age I would put it as upper Middle or lower Upper Cambrian.

[41] Wichman, F. M., op. cit., p. 560.
[42] Olmstead, S. G., op. cit., p. 440.
[43] Loughlin, G. F., op. cit. (Prof. Paper 107), p. 28.

MIDDLE (?) AND UPPER CAMBRIAN SERIES

LYNCH DOLOMITE

Distribution and topographic expression.—Conformably overlying the Bowman limestone is a thick series of dominantly massive gray dolomites, here called, from its exposures on Lynch Ridge, the Lynch dolomite. The Lynch dolomite crops out on the south wall of Ophir Canyon southeast of Ophir, where it forms much of the canyon wall from the old tailing dumps a mile below the town to the baseball park. On the north side of Ophir Creek the dolomite is exposed in a belt extending from the baseball park to the spur northeast of the Ophir Central shaft and then curving successively northwest, west, and southwest around the outcrops of the older rocks. It forms the divide between Dry and Ophir Canyons from a point near the old Chicago mine to a point a short distance west of the summit of Dry Mountain, west of Ophir. The Canyon fault here cuts the outcrop off on the south. The formation forms the southeast wall of Dry Canyon from a point a short distance below the buildings of the Hidden Treasure mine nearly to the mouth.

Stratigraphy.—The lower beds of the Lynch dolomite are apparently conformable upon the Bowman limestone. As was stated in the description of the Bowman limestone, the boundary is far from satisfactory. Rapid local changes, apparently unrelated to fissures, occur within the lower beds of this unit, so that a given bed may change from limestone to dolomite within less than 50 feet. Sections measured within 100 yards along the strike and assuredly uncomplicated by faulting showed variations of more than 80 feet in the stratigraphic position of the lowest dolomite beds. To some extent this variability is doubtless due to interfingering of dolomite and limestone lenses, but there is actual variation within individual beds also, as can be seen near Lynch Ridge east of the Cliff mine. The lowest beds of dolomite on this ridge when followed westward are seen to change to limestone within 200 feet. Messrs. Hartmann and Bowman, of the Ophir Hill Consolidated Mining Co., informed the writer that painstaking detailed work on their part showed this to be a characteristic feature. The present survey bears out their observations on this point, as has been shown in the section describing the Bowman limestone.

The lower part of the Lynch dolomite is an alternating series of limestone and dolomite, but a short distance above the base a rather unusual variety of rock occurs. This is a dark steel-gray crystalline dolomite, weathering almost black except for a spangling of white rods and vermicular tubelike markings which average perhaps one-sixteenth of an inch in diameter and are a quarter to half an inch in length. The rock is practically identical in appearance with the Bluebird dolomite of the Tintic district, and Bluebird is the name locally applied to it. Unfortunately, so far as accurate geologic mapping is concerned, the lithology is not limited to a single zone but occurs in zones of varying thickness and stratigraphic position from place to place. However, it is useful to the extent that it marks a zone rather low in the dolomite series—in some places the very base itself, as in the Tintic district. A hand specimen of this peculiar rock is illustrated in Plate 6, *B*.

The upper three-fourths of the Lynch dolomite is composed of rather thick-bedded light-gray and dark-gray dolomites, the former predominating, in somewhat massive beds which only exceptionally show thin bedding. Distinctive beds are rare and probably discontinuous; at least careful studies failed to identify any single horizon on both sides of Ophir Canyon. Magnesian limestones occur here and there, but they are decidedly subordinate. A finely laminated light-gray dolomite which weathers dull chalky white is rather common in the formation and makes good local marker beds. An example is illustrated in Plate 6, *C*.

The following section was measured on Lynch Ridge east of the Cliff mine and is considered representative of the formation:

Section of Lynch dolomite east of Cliff mine

[Strike N. 65° W.; dip 17° NE.]

	Feet
Jefferson(?) dolomite: Thin limy sandstone at base. Unconformity, showing slight irregularity but traced with difficulty.	
Lynch dolomite:	
1. Thin-bedded light-gray dolomite	23
2. Light-gray dolomite in beds, 4 to 10 feet thick, forming very steep cliffs	374
3. Gray dolomite, in beds 3 to 4 feet thick; a little magnesian limestone at the base	44
4. Dark-gray finely crystalline dolomite, in beds ranging from 1 to 7 feet in thickness. Forms a strong ledge, the top 1-foot bed of which is conspicuously black	19
5. Light-gray, very dense dolomite which is conspicuously white and finely banded on weathering. (See pl. 6, *C*.)	4½
6. Light-gray with subordinate dark-gray dense dolomite	29
7. Blue-gray limestone with white shale partings. Trilobite fragments were found in this member	57½
8. Rather coarsely crystalline dark-gray dolomite, which weathers nearly black. Contains short rods of white dolomite spangled throughout, which are probably organic remains of uncertain affinities. Bluebird type. (See pl. 6, *B*.)	29
9. Alternating limestone and light-gray dolomite in thin beds	11
10. Limestone, light blue-gray, mottled with irregular white-weathering shaly streaks	15

Lynch dolomite—Continued.	Feet
11. Light-gray dense dolomite, weathering almost white and with finely streaked surfaces, like No. 5	5
12. Dense blue magnesian limestone mottled with thin irregular streaks of white-weathering shaly material	21
13. Gray mottled dolomite	15
14. Dark-gray dolomite, like bed 8; Bluebird type	20
15. Blocky siliceous shale	½
16. Dark-gray dolomite, like bed 8; Bluebird type	31
17. Poorly exposed blue mottled limestone	18
18. Massive blue limestone mottled with light-gray shaly material	4½
19. Chert parting	¼
20. Limestone, dark blue, streaked with a few thin shaly streaks and with numerous vermicular tubes of coarsely crystalline calcite. Poorly exposed	35½
21. Dark-blue limestone, dense and streaked with thin discontinuous white shaly layers and carrying white rodlike markings like the Bluebird type of dolomite	64½
22. Dark-gray dolomite like bed 8; Bluebird type	6
Conformable contact.	827¼
Bowman limestone: Dark blue-gray limestone, streaked with irregular white crystalline calcite markings roughly parallel to the bedding, carrying sporadic nearly black oolites and numerous scattered cylindrical rods of calcite.	

The Lynch dolomite is well exposed on the south side of Ophir Canyon, and a section was measured here from the portal of the new Ophir Hill tunnel to the base of the Jefferson (?) dolomite about half a mile below the town. Owing to the Lion Hill fault it is impossible to get a complete section directly south of the Ophir Hill portal on the anticlinal axis, and the measurement as made is doubtless not very exact, as changing dips and slight uncertainties in stratigraphic tracing as well as the steep slopes with many low vertical cliffs that were encountered all hindered accurate work. This measurement gave approximately 900 feet as the thickness of Lynch dolomite exposed. Dolomite was found in the new Ophir Hill shaft to depths of about 150 feet, which would give a total of 1,050 feet of Lynch dolomite on the south side of the canyon as compared with 827 feet on the north side, a difference of over 200 feet in less than 1 mile. Even when the inaccuracies of compass and tape surveys are taken into account, this difference seems to indicate considerable lateral variation of the formation. This variation may be in large part due merely to lithologic change, but as there is an uncomformity at the top of the formation, it seems not unreasonable to ascribe some of the changes to differential erosion in pre-Devonian time.

The upper limit of the Lynch dolomite is put at the base of a thin sandstone bed that separates beds of very similar overlying dolomites, which, however, carry a Devonian fauna, whereas the Lynch dolomite is of Upper and Middle Cambrian age.

Age and correlation.—A single collection of fossils was made from the Lynch dolomite, at a horizon about 280 feet from the base on Lynch Ridge. This collection was submitted to Dr. C. E. Resser for identification, and he reports as follows:

> Locality F16, containing numerous *Hyolithes*, would seem to be Upper Cambrian, but that is not certain.

Correlation of the dolomite section at Ophir with that at Tintic is very tempting, owing to the remarkable similarity of individual rock types in the two districts. There is undeniably a strong resemblance between many dolomite beds of the Ophir district—for example, Nos. 8, 14, 16, and 22 of the above section—and the Bluebird dolomite at Tintic. However, at Ophir these beds do not occur in thick sections of uniform lithology as they do at Tintic, but are interbedded with limestones and other dolomites through a thickness of over 275 feet in the section most carefully studied by the writer. Wichman [44] puts 600 feet of the dolomite series into the Bluebird as he defines it, whereas his coworker Olmstead [45] limits the Bluebird to 140 feet. The writer hesitates to make the correlation at all on the basis of lithology only, especially as dolomite of the Bluebird type interfingers with mottled limestone at the base in this area, so that closely adjacent sections show variations of 100 feet or more in the stratigraphic position of the lowest representative of the type. Similar and even more striking variations occur in the Bluebird type of dolomite in the Deep Creek Range, 100 miles to the west, where they have been studied by Nolan.[46] In view of these variations, the writer does not designate any formation as Bluebird dolomite in the Ophir district but includes the dolomite of Bluebird lithology with the overlying dolomites in one formation, the Lynch dolomite. It seems probable that the Lynch dolomite as here defined includes beds equivalent, at least in part, to the Bluebird, Cole Canyon, and perhaps Opex dolomites of Tintic, but as already shown, no boundary between the two lower units can be established in this area, and no clear and constant distinctions were recognized by the writer in the upper beds which might serve as a basis for dividing the formation into two upper units equivalent to the Cole Canyon and Opex dolomites. The Lynch dolomite, except for the beds of Bluebird type, resembles the Cole Canyon of Tintic throughout, and no beds resembling the Opex were noted here. This does not support the correlation offered by Olmstead of 530 feet of the dolomite with the Cole Canyon and 218 feet with the Opex.

[44] Wichman, F. M., op. cit., p. 560.
[45] Olmstead, S. G., op. cit., p. 441.
[46] Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation).

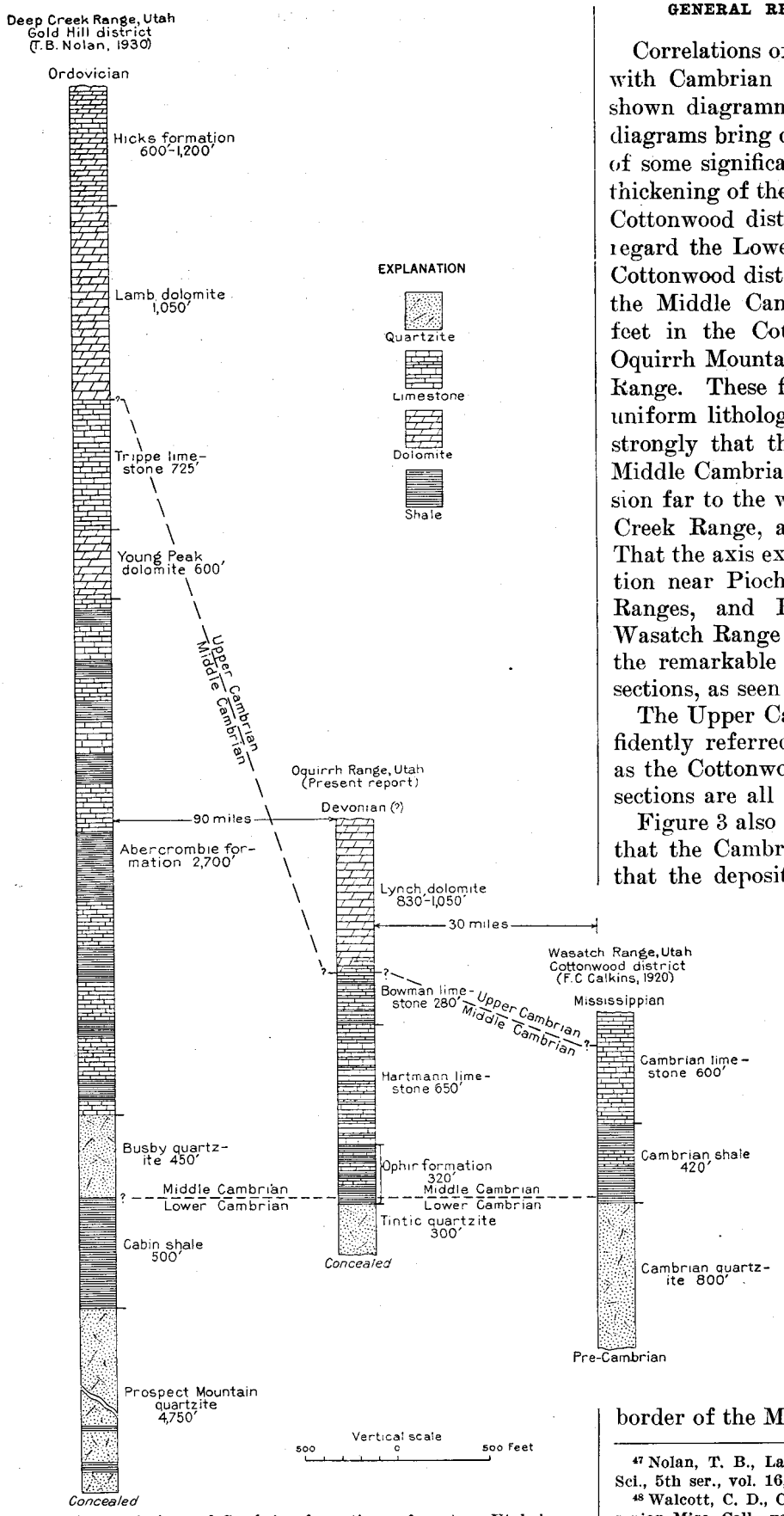


FIGURE 2.—Variations of Cambrian formations of western Utah in a west-east direction in the latitude of Ophir

GENERAL RELATIONS OF THE UTAH CAMBRIAN

Correlations of the Cambrian of the Oquirrh Range with Cambrian rocks of other districts in Utah are shown diagrammatically in Figures 2 and 3. These diagrams bring out a number of regional relationships of some significance. Figure 2 shows the remarkable thickening of the Cambrian section westward from the Cottonwood district of the Wasatch Range. To disregard the Lower Cambrian, of which, except in the Cottonwood district, the base is everywhere concealed, the Middle Cambrian shows in round numbers 800 feet in the Cottonwood district, 1,200 feet in the Oquirrh Mountains, and 4,300 feet in the Deep Creek Range. These figures, in connection with the fairly uniform lithology of all three sections, suggests very strongly that the area of maximum deposition—the Middle Cambrian geosyncline—had its axis of depression far to the west, in the neighborhood of the Deep Creek Range, as has been pointed out by Nolan.[47] That the axis extended in a north-northeasterly direction near Pioche, Nev., the Deep Creek and House Ranges, and Blacksmith Fork, in the northern Wasatch Range of Utah, is very probable, in view of the remarkable similarities in thickness of all these sections, as seen in Figure 3.

The Upper Cambrian variations can not be so confidently referred to original depositional differences, as the Cottonwood, Oquirrh, Tintic, and Deep Creek sections are all limited at the top by unconformities.

Figure 3 also brings out a point made by Walcott[48] that the Cambrian sea advanced from the south, so that the deposition of coarser clastic materials persisted in the northerly areas to a much later date than in the southerly areas, which, correspondingly, earlier became the seats of offshore sedimentation.

PRE-MIDDLE DEVONIAN UNCONFORMITY

An unconformity limits the Lynch dolomite at the top, separating it from the overlying Jefferson (?) dolomite, as described later. This unconformity represents a time interval including the Ordovician, Silurian, and part of the Devonian, so that in the Oquirrh Mountains, Middle (?) Devonian beds rest directly upon the Upper Cambrian. The sections of Figures 2 and 3 show either that the Oquirrh locality, near the border of the Middle Cambrian and Upper Cambrian

[47] Nolan, T. B., Late Paleozoic positive area in Nevada: Am. Jour. Sci., 5th ser., vol. 16, pp. 153–161, 1928.

[48] Walcott, C. D., Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., vol. 53, No. 5, p. 191, 1908; Problems of American geology, p. 170, New Haven, 1915.

geosyncline, was never the seat of important sedimentation during this interval or that the deposits of these periods have been here eroded. In the other districts

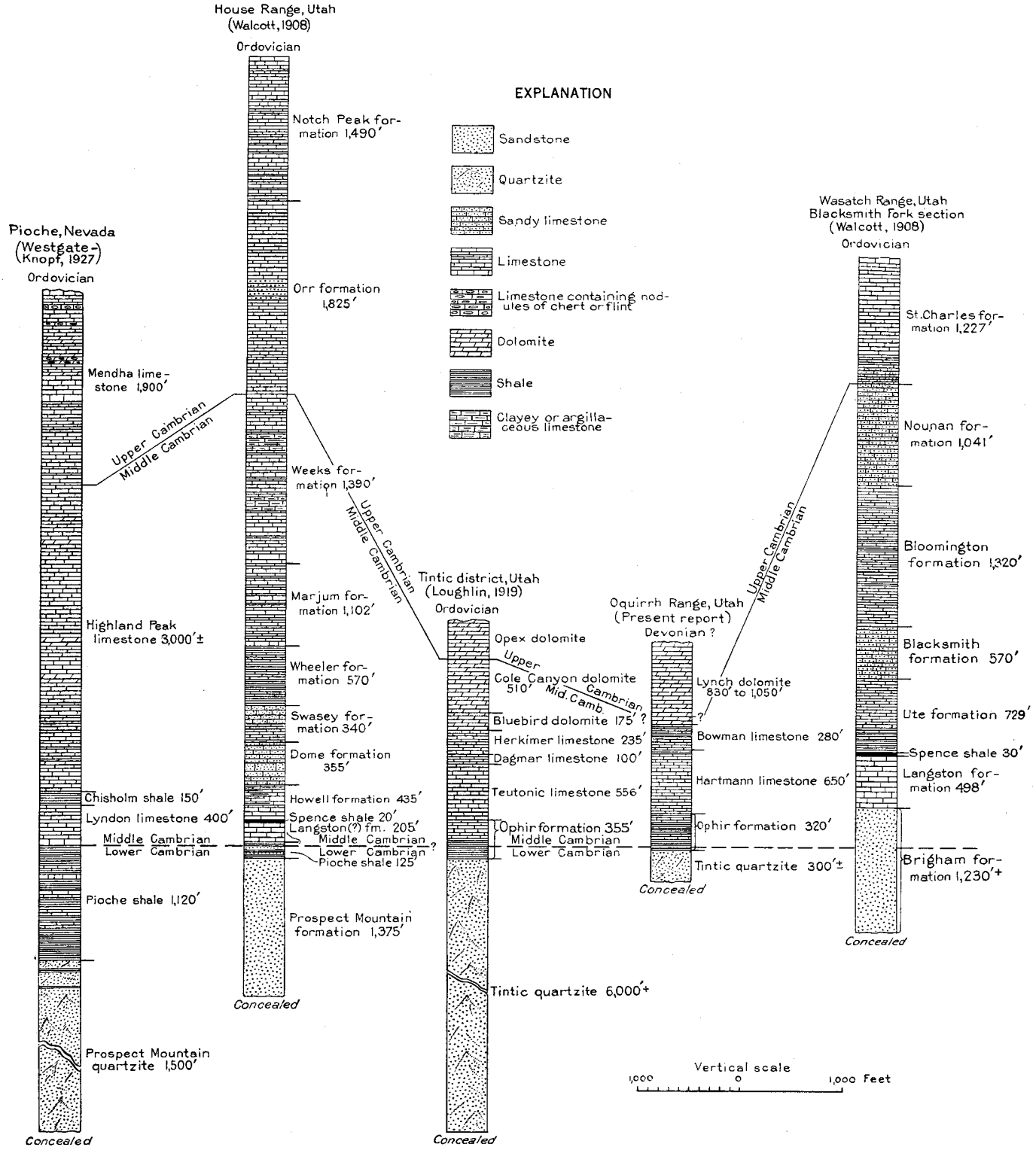


FIGURE 3.—Variations of Cambrian formations of western Utah and southeastern Nevada in a southwest-northeast direction

the Upper Cambrian is succeeded by Ordovician rocks, but in the Oquirrh Mountains the lowest post-Cambrian rocks represented are Devonian, and in the central part of the Wasatch Range Mississippian.

Abundant evidence has been marshaled by Loughlin [49] to show notable erosion in central Utah during post-Cambrian and pre-Mississippian time. The major part of this erosion is assigned by him to late Devonian pre-Mississippian time, an assignment which

[49] Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 36–38, 1919.

seems eminently suitable. However, there is definite local evidence that some of this erosion occurred earlier than Middle Devonian time. Much of the evidence of erosion adduced by Loughlin can be interpreted, as he recognized, to indicate pre-Devonian as reasonably as post-Devonian emergence, and the absence of Silurian rocks at Tintic and of both Silurian and Ordovician rocks at Cottonwood and Ophir Canyons, with the presence of Devonian at Tintic and Ophir, points clearly toward this region as being of positive tendencies in pre-Devonian time.

The absence of late Silurian and of Lower Devonian at Gold Hill, Utah,[50] indicates that the entire region may have been emergent just prior to the Middle Devonian. In the absence of more detailed information from other districts in central and western Utah, further discussion is hardly profitable; suffice it to point out that future work may well demonstrate that the fourth (pre-Middle Devonian) period of erosion in pre-Mississippian time recognized by Loughlin[51] at Tintic was of much more than local significance. The erosion may indeed have been fully as widespread as the post-Devonian erosion, but this remains to be demonstrated.

DEVONIAN SYSTEM

MIDDLE (?) DEVONIAN SERIES

JEFFERSON (?) DOLOMITE

Distribution and topographic expression.—The Lynch dolomite is unconformably overlain by the Jefferson (?) dolomite. This formation crops out just above the Lynch dolomite, forming steep cliffs with slight benches beneath them. Such cliffs and benches occur on both sides of Ophir Canyon and in Dry Canyon, without any breaks except such as are due to the faults which have been mentioned as offsetting the Lynch dolomite outcrops.

Stratigraphy.—The lowest bed of the Jefferson (?) dolomite is a fine-grained soft shaly and dolomitic sandstone whose softness and general textural similarity to the beds between which it lies unite in making it inconspicuous. It is highly probable that the dolomites here referred to, the Jefferson (?), would not have been differentiated from the Lynch except that the identification of post-Cambrian fossils within them by Edwin Kirk led him to search for evidence of a stratigraphic break below. Close search was rewarded by the identification of this thin clastic bed, whose lower surface is seen to be somewhat irregular. Shaly fragments and quartz grains occur in it, but it is composed chiefly of dolomite sand. Once discovered by Mr. Kirk, he and the writer were able to recognize the horizon at each place at which search for it was made, but the boundary as shown on the map was not actually traced in detail, because the interval between it and the easily followed contact at the top of the formation is so slight and the variations observed in this interval are so nearly negligible. Accordingly the establishment of a dozen or so control points for the basal contact sufficed to permit its delineation by reference to the upper contact, at least within the limit of error permissible on the scale of the accompanying map.

The most characteristic lithologic feature of the formation is exhibited by a very massive bed a short distance below the top. This bed consists of crystalline very dark gray dolomite, with almost no discernible tendency toward bedding, which carries numerous white blebs of calcite. These white calcite masses are very conspicuous, standing out in distinct contrast to their dark matrix. They range from about a quarter of an inch to 2 inches, or even, exceptionally, 3 inches in diameter. Their shapes are reminiscent of some large pentameroid brachiopod, but diligent search failed to bring to light any identifiable forms, and it is even doubtful that they are organic, although no other explanation of their presence is apparent. The bed is useful for stratigraphic tracing and is locally called the "eye bed" because these "eyes" are so conspicuous. A specimen of the rock composing the bed is illustrated in Plate 6, *A*.

The Jefferson (?) dolomite is limited upward by an unconformity upon which rest the basal beds of the Madison limestone, of lower Mississippian age. The following section is a continuation of the measured section of the Lynch dolomite:

Section of Jefferson (?) dolomite on spur east of Cliff mine

	Feet
Madison limestone: Thin-bedded bluish-gray crystalline, highly fossiliferous limestone.	
Unconformity, marked by chert pebbles and a typical small-scale karst topography (illustrated in fig. 4).	
Jefferson (?) dolomite:	
1. Gray massive coarsely crystalline dolomite, in one bed	40
2. Dark-gray coarsely crystalline massive dolomite, weathering almost black, with large oval calcite blebs conspicuously distributed throughout. Passes upward by the gradual elimination of the blotches into bed 1. Locally called the "eye bed" in reference to the calcite blotches	75
3. Medium-gray finely crystalline dolomite, weathering dark gray, in beds ranging from 2 to 8 inches in thickness	45
4. Massive white siliceous limestone, poorly bedded and not well exposed	17
5. Poorly exposed soft sandstone, alternating in layers about 2 or 3 inches thick with limestone. The sandstone is gray, weathering with slight reddish to brownish tinges, poorly bedded, somewhat shaly, fine grained, probably in large part composed of reworked dolomitic sand	8
Unconformity, a slightly wavy surface.	185
Lynch dolomite: Thin-bedded light-gray dolomite at top.	

[50] Nolan, T. B., op. cit. (in preparation).
[51] Loughlin, G. F., op. cit., p. 34.

Age and correlation.—The Jefferson (?) dolomite has yielded, from the massive "eye bed," a number of poorly preserved fossils upon which Mr. Kirk reports as follows:

> Lot Gy–26–15. Dolomitic limestones overlying the Cambrian and underlying the highly fossiliferous Mississippian. Collected in the main near the ball park, east side of Ophir, Utah:
>
> Cyathophyllum sp.
> Syringopora, 2 species.
> Spirifer sp.
>
> The preservation of the material is so poor that accurate determination of the fossils is out of the question. However, the fossils of this lot suggest Devonian rather than Mississippian. The lithology of the beds is that of the Middle Devonian (Jefferson limestone and its equivalents), at variance with the Mississippian as known. Moreover, the field relations of this horizon with the overlying typical Mississippian indicate a time break of considerable magnitude. Taking all these factors into consideration it seems reasonably safe to assign the beds to the Middle Devonian.

Rocks of Upper Devonian age (the Pinyon Peak limestone) have been reported from the Tintic district,[52] but they are limestones instead of dolomites as at Ophir, and though of comparable thickness (about 150 feet) they have been tentatively assigned to the Upper Devonian (Three Forks) instead of Middle Devonian (Jefferson). It is possible that Devonian dolomites of Jefferson age are present in the upper 400 feet of the underlying Bluebell dolomite at Pinyon Peak, in the Tintic district, but no fossils were found in them, and the possibility that they may be of Jefferson age is the most that can be suggested.

South and west of Tintic the next place from which Devonian rocks have been described is the San Francisco district, Utah.[53] Here the only fossils collected were determined as presumably correlating the Mowitza shale with the upper part of the Jefferson. No unconformities were found in the section, and, as Butler states, it is not known how much of the underlying Red Warrior limestone is also Devonian. Possibly several hundred feet of the overlying Topache limestone is also Devonian, although Butler believed that its lithology suggested that it is all of Mississippian age, as the upper part is known to be.

In the Deep Creek Range, about 90 miles west of the Oquirrh Mountains, from 2,350 to 2,850 feet of dolomite, with subordinate limestone and sandstone, has been assigned to the Middle Devonian.[54] Possibly the Jefferson dolomite is to be correlated with some part of this section, but in the present state of our knowledge such correlation must be considered only possible, not probable. No other sections in Utah west of the Oquirrh Mountains have been studied sufficiently to determine the presence or absence of beds equivalent to the Jefferson.

The Jefferson dolomite is probably represented in the Wasatch Range north of Ogden,[55] but the fossils from Big Cottonwood Canyon referred to the Devonian by Hintze[56] are actually of Mississippian age.[57]

Schneider[58] refers casually to Devonian rocks at Neffs Canyon, near Salt Lake City, but he gives no faunal list, apparently basing his age determinations on correlations with the Cottonwood district. Hence, this determination can be regarded as questionable. No other Devonian rocks have yet been recognized in the Wasatch Range south of Salt Lake City.[59]

In the Randolph quadrangle, in northern Utah, the Jefferson dolomite is prominently developed,[60] resting with apparent conformity upon the Laketown dolomite, of Silurian age. In the Randolph quadrangle the formation is overlain with probable conformity by the Threeforks limestone, of Upper Devonian age, and the Threeforks is in turn apparently conformable beneath the Madison limestone. The Jefferson consists of dense dark-gray, dominantly massive dolomite, with some thin beds toward the base.

The dolomites lying unconformably above the Cambrian at Ophir are dense, dark gray, and massive—according to Kirk, lithologically very like the Jefferson of the Randolph quadrangle. They lie unconformably beneath the fossiliferous limestone with a characteristic Madison fauna, which is, throughout the Rocky Mountain region, as far as known, the earliest representative of the Mississippian. The meager and unsatisfactory faunule collected from these dolomites appears to indicate a Middle Devonian age, and, on account of the lithologic similarity, it is suggested that the rocks at Ophir are equivalent to part of the Jefferson dolomite. The element of uncertainty in the extension of such a correlation over the interval (about 80 miles) between the Randolph quadrangle and Ophir, without adequate study at intermediate points, it seems best to express by placing a query after the name. The southward and westward continuation of even this tentative correlation seems at present impossible. It is distinctly possible that this area marks the approximate limit of the Jef-

[52] Loughlin, G. F., op. cit. (Prof. Paper 107), pp. 36–38.
[53] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 29–35, 1913.
[54] Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation).
[55] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 527–528, 1910.
[56] Hintze, F. F., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 108–109, 1913.
[57] Kirk, Edwin, oral communication.
[58] Schneider, Hyrum, A discussion of certain geologic features of the Wasatch Mountains: Jour. Geology, vol. 33, pp. 36–37, 1925.
[59] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains: Jour. Geology, vol. 21, pp. 436–452, 1913.
[60] Kindle, E. M., The fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Bull. Am. Paleontology, vol. 4, No. 20, pp. 14–18, 1908. Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 406, 411, 1913.

ferson in this direction, but it would be premature to express so definite a limit.

PRE-MISSISSIPPIAN UNCONFORMITY

The presence of a pre-Mississippian unconformity in Utah has been emphasized by Loughlin.[61] In the Stockton and Fairfield quadrangles the base of the Mississippian rocks is exposed for only about 4 miles and over this distance gives little evidence of either angular unconformity or significantly variable depth of erosion in the pre-Mississippian rocks. Nevertheless, there is ample local evidence of erosion and sea transgression in the Oquirrh Mountains, and the regional evidence of a significant break at this horizon is entirely convincing.

The pre-Mississippian erosion is very clearly indicated by the contact of the Madison limestone with the Jefferson (?) dolomite. This contact appears to represent a preserved karst topography, the top of the coarsely crystalline gray Jefferson (?) dolomite having a relief of fully 2 feet in many places and being marked by scattered solution cavities as much as 6 feet deep, now filled with the dense blue-gray limestone of the Madison. Figure 4 represents common features of the contact. At some places there are pebbles of dolomite and black chert in the base of the Madison, and the maximum observed thickness of this pebble bed is about 1 foot.

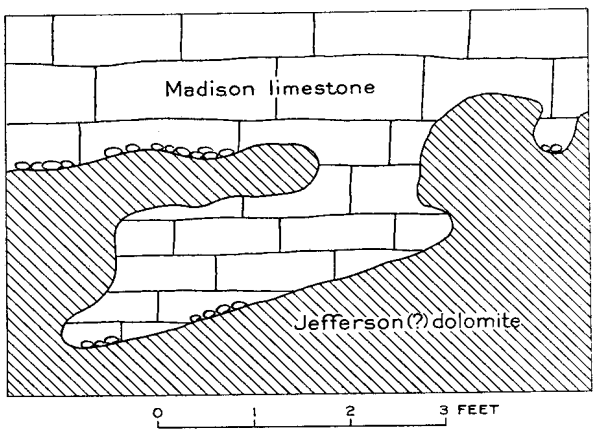


FIGURE 4.—Detail of contact between Jefferson (?) dolomite and Madison limestone, showing typical small-scale karst topography of the contact surface

In the Uinta Range the Mississippian overlaps the Ordovician and rests directly on the Cambrian.[62] Whether the erosion thus indicated was chiefly pre-Devonian or post-Devonian, however, is not surely known. No unconformity has been definitely recognized between the Devonian and Mississippian in southeastern Idaho[63] and northeastern Utah,[64] but a doubtful one near Ogden has been referred to by Blackwelder[65] with the suggestion that it is probably unimportant. This unconformity may be within rather than beneath the Mississippian, according to Blackwelder.

Just north of Salt Lake City the Mississippian rests upon the Upper Devonian,[66] but a short distance to the south, at Big Cottonwood Canyon, it rests directly upon beds at widely varying horizons in the Cambrian,[67] indicating significant post-Cambrian erosion, which, however, may have been in part pre-Devonian rather than all post-Devonian. Between Big Cottonwood Canyon and Mount Nebo, Loughlin[68] discovered the Mississippian limestones resting on varying thicknesses of pre-Mississippian limestones, perhaps locally on the Ophir formation itself. At Tintic the Mississippian begins with a clastic member, the Victoria quartzite, and rests in some places on Upper Devonian and elsewhere on Ordovician beds.[69] This is clearly due to an erosional unconformity, as is confirmed by the relations in the Oquirrh Mountains, described above, and in the southern part of the Wasatch Range. Still farther south, in the San Francisco district, Butler[70] was able to detect no unconformity between the Mississippian Topache limestone and the Devonian Mowitza shale, but the fossils from the Topache suggest a post-Madison age, which may indicate an unconformity, with the omission of the lower Mississippian.

In the Gold Hill quadrangle Nolan[71] has found evidence of pre-Mississippian unconformity, with the upper Mississippian overlapping a wedge of Madison limestone and resting directly on Middle Devonian. From Gold Hill westward there is strong evidence of orogeny in late Devonian or Carboniferous time in western Nevada.[72]

The pre-Mississippian unconformity is accordingly seen to be, as suggested by Loughlin, of widespread occurrence and significance.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SERIES

MADISON LIMESTONE (LOWER MISSISSIPPIAN)

Distribution and topographic expression.—The Madison limestone crops out on the north wall of Ophir Canyon above the belt of Jefferson (?) dolomite at the Cliff mine and, forming a rather less pre-

[61] Loughlin, G. F., op. cit. (Prof. Paper 107), pp. 36–38.

[62] Weeks, F. B., Stratigraphy and structure of the Uinta Range: Geol. Soc. America Bull., vol. 18, p. 438, 1907.

[63] Mansfield, G. R., Geography, geology, and mineral resources of a part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 182, 1927.

[64] Richardson, G. B., Am. Jour. Sci., 4th ser., vol. 36, p. 412, 1913.

[65] Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey Bull. 430, p. 539, 1910.

[66] Kirk, Edwin, and Mathews, A. A. L., oral communications.

[67] Calkins, F. C., in Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 237–238, 1920.

[68] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains: Jour. Geology, vol. 21, pp. 444–447, 1913.

[69] Loughlin, G. F., U. S. Geol. Survey Prof. Paper 107, pp. 37, 39, 1919.

[70] Butler, B. S., U. S. Geol. Survey Prof. Paper 80, pp. 35–36, 1913.

[71] Nolan, T. B., op. cit.

[72] Nolan, T. B., A late Paleozoic positive area in Nevada: Am. Jour. Sci., 5th ser., vol. 16, pp. 153–161, 1928.

cipitous slope than that formation, swings over the divide into Dry Canyon, where it forms much of the lower part of the north wall as far as the mouth. Here its outcrop crosses the canyon and forms a wedge-shaped area on the west slope of the hill between Dry Canyon and the west end of the Canyon fault. South of the Canyon fault the Madison limestone forms much of the prominent spur southeast of Dry Mountain west of Ophir, and its outcrop forms a U-shaped area extending between the Canyon fault on the north and the Lion Hill fault on the south, with its base pointing downstream in conformity to the westerly dip on this portion of the Ophir anticline. Along much of the course of the Lion Hill fault the Madison limestone is dropped from sight, though there are some "slivers" of the formation caught in as horses along the fault. Northeast of the small knoll where the trail from Long Trail Gulch passes into Ophir Canyon the Madison forms a continuous belt down into Ophir Canyon, which it reaches south of the baseball park. North of the baseball park the formation is offset about 1,000 feet by the several branches of the Canyon fault, but northwest of them its outcrop is uninterrupted by faults of consequence except the Cliff fault, which cuts it in the Cliff mine workings.

Stratigraphy.—The Madison limestone rests on the Jefferson (?) dolomite without notable angular discordance but with very clear and unmistakable unconformity, as shown by the distinct karst topography (fig. 4) already described. At some places there are pebbles of dolomite and black chert in the base of the Madison, and the maximum thickness of this pebble bed is about 1 foot.

The Madison limestone is a bluish-gray dense limestone, easily distinguished from all the underlying limestones by its freedom from mottling of any sort. It is of considerable economic importance, as the basal part is ore bearing in the Buckhorn mine.

The following section, which is a continuation of the section of the Jefferson (?) dolomite, is considered typical of the formation as developed in the Ophir district:

Section of Madison limestone on ridge east of Buckhorn mine

[Strike N. 60° W.; dip 28° N.]

	Feet
Deseret limestone: Dense blue-gray limestone, with a soft carbonaceous and phosphatic shale at base.	
Conformable contact.	
Madison limestone:	
1. Very cherty blue-gray limestone. The black chert is arranged in lenses, which average 6 inches apart stratigraphically and are as much as 6 feet long and 3 inches thick	55
2. Gray blocky limestone, in beds averaging about 2 inches thick. The member is much viened with calcite and is more coarsely granular than bed 1. Little or no chert is present	29
Fault of unknown but probably slight displacement.	
Madison limestone—Continued.	Feet
3. Cherty blue-gray limestone, rather massive below, somewhat thinner bedded above. Black chert lenses occur within the individual limestone beds as well as between them. The chert lenses are spaced perhaps 2 feet apart stratigraphically and range from knife-edges to 2½ inches in thickness and several feet in length. The limestone beds are considerably broken and recemented with white calcite. The member forms a ledge	109½
4. Very light bluish-gray dense limestone, very fossiliferous, pure except for subordinate brown shaly streaks, thin bedded at the base, where the beds range from 1 to 5 inches in thickness, but becoming thicker bedded and somewhat more coarsely crystalline upward. Some of the beds near the top are as much as 8 feet thick	268½
	462
Irregular surface of unconformity.	
Jefferson (?) dolomite: Light-gray dolomite at top.	

Age and correlation.—Fossils from the Madison limestone have been reported on by G. H. Girty as follows:

The lowest of the Carboniferous formations recognized is the Madison limestone, from which we have seven collections, 1 made in 1925 by Paige, 6 made in 1926 by Gilluly and Kirk, and 1 in 1927 by Girty. These lots have essentially the fauna of the Madison limestone and are of early Mississippian age.

5799. Limestone below the heavy chert member of the Madison limestone, Ophir Creek, north side, near road, Ophir, Utah; collected by Sidney Paige:

Triplophyllum sp.	Pustula sp.
Cystodictya sp.	Camarotoechia sp.
Rhipidomella sp.	Dielasma sp.
Schizophoria aff. S. sedaliensis.	Spirifer centronatus.
Leptaena analoga.	Syringothyris aff. S. newarkensis?
Schuchertella aff. S. chemungensis.	Reticularia cooperensis.
Chonetes loganensis.	Cliothyridina aff. C. glenparkensis.
Productus aff. P. sedaliensis.	Hustedia circularis?
Productus ovatus.	Euomphalus utahensis.
Productus aff. P. sampsoni.	Euomphalus utahensis var.
Productus parviformis.	Straparollus sp.
Pustula patula?	Platyceras sp.

6015. Within 50 feet of the base, Madison limestone on Lynch Ridge, east of Cliff mine, Ophir Canyon, Utah; collected by James Gilluly:

Triplophyllum excavatum.	Spiriferina solidirostris.
Syringopora surcularia.	Straparollus ophirensis.
Fenestella sp.	Euomphalus luxus.
Spirifer centronatus.	Loxonema sp.

6015A. Same locality as 6015; collected by James Gilluly and M. J. Buerger:

Schuchertella chemungensis.	Spirifer centronatus.
Chonetes loganensis.	Spiriferina solidirostris.
Productus sp.	Euomphalus luxus.

6016. Middle of Madison limestone 500 feet southwest of mineral monument No. 4, Ophir Canyon and Dry Canyon divide, Stockton quadrangle; collected by James Gilluly:

Triplophyllum excavatum.	Spirifer centronatus.
Schuchertella chemungensis.	Composita humilis.
Chonetes loganensis.	Eumetria verneuiliana.
Pustula sp.	

6017. Base of Madison limestone, 200 yards northwest of ball park, Ophir Canyon, Stockton quadrangle; collected by Edwin Kirk:

Syringopora surcularia.	Composita humilis.
Aulopora sp.	Cliothyridina crassicardinalis.
Triplophyllum excavatum.	Eumetria verneuiliana.
Cyathophyllum sp.	Parallelodon sp.
Cyathophyllum? sp.	Aviculipecten sp.
Lithostrotion n. sp.	Conocardium? sp.
Echinocrinus sp.	Laevidentalium aff. L. venustum.
Schuchertella chemungensis.	
Chonetes loganensis.	Bucanopsis aff. B. deflecta.
Productus ovatus.	Platyceras sp.
Productus gallatinensis.	Naticopsis sp.
Productus aff. P. arcuatus.	Euomphalus luxus.
Productus sp.	Straparollus utahensis.
Pustula n. sp.	Sphaerodoma? sp.
Camarotoechia metallica.	Cyclonema sp.
Girtyella? sp.	Loxonema n. sp.
Spirifer centronatus.	Griffithides sp.
Spiriferina solidirostris.	Paraparchites sp.

6021. Collected from limestone just below the shale in which is located the Fisk mine, north side of Ophir Canyon, 1 mile above Ophir, Fairfield quadrangle; collected by Edwin Kirk, M. J. Buerger, and James Gilluly:

Triplophyllum sp.	Spirifer centronatus.
Crinoid fragments.	Spirifer mysticensis.
Schizophoria aff. S. compacta.	Brachythyris aff. B. gurleyi.
Schuchertella chemungensis.	Composita monticola?
Chonetes illinoisensis.	Aviculipecten sp.
Productus gallatinensis.	

6255. About 200 feet above the base of Madison limestone, north side of Ophir Creek, west of Ophir, above old tailing dump; collected by G. H. Girty:

Zaphrentis sp.	Spirifer centronatus.
Lithostrotionella n. sp.	

The type locality of the Madison limestone is in the Madison Range, in western Montana, but its characteristic lithology and fauna have justified the extension of the name through southeastern Idaho [73] to northern Idaho.[74]

In the Cottonwood district of the Wasatch Range limestone carrying the typical Madison fauna and of comparable lithology with the type Madison have been referred to that formation by Calkins.[75] In view of the fossil evidence as reviewed above by Girty, it seems thoroughly justifiable to refer the rocks in the Oquirrh Mountains to the Madison limestone as well.

The Madison is also recognized in the Deep Creek Range, Utah,[76] where it is overlapped by rocks of upper Mississippian age.

In the Tintic district [77] the Gardner dolomite carries fossils of Madison age, which, with the unconformity beneath the Victoria quartzite, support a correlation of the Gardner dolomite and Victoria quartzite with these rocks, although the lithology of the sections is quite different. It seems highly probable that the Victoria quartzite, Gardner dolomite, and Pine Canyon limestone of Tintic are equivalent, at least in part, to the Madison and Deseret limestones of the Ophir district, as here defined. The fact that both the Madison limestone of the Ophir district and the Gardner dolomite of Tintic are succeeded by black shale suggests that the Pine Canyon limestone of Tintic may be wholly later than the Madison. Only Brazer fossils have been found in the Pine Canyon limestone, and as the cherty character of some of its lower beds can be duplicated in the post-Madison limestones of the Oquirrh Mountains this character can hardly of itself prove the Madison age of these lower beds, as was tentatively suggested by Loughlin from comparison of the Tintic section with the Mississippian of the southern part of the Wasatch Range. However, the continuity of so thin a shale as the one succeeding the Madison in the Oquirrh Mountains is so doubtful that the occurrence of a shale in both sections at comparable horizons can hardly be held to disprove Loughlin's tentative assignment of a Madison age to the lower part of his Pine Canyon limestone. Nevertheless, the parallelism between the two sections is suggestive.

Loughlin suggested, because of their lithologic similarity, that the black shale bed at the base of the Pine Canyon limestone and a thinner shale bed in the underlying Gardner dolomite might be equivalent to the two shale beds at Mercur described by Spurr,[78] but the lower shale at Mercur belongs to the "Great Blue" limestone and is much higher stratigraphically.

The correlation suggested by Olmstead [79] made the lower part of the Madison limestone as here limited equivalent to part of the Ajax limestone (Ordovician) of Tintic (which the fossil evidence immediately negatives) and the rest of the Madison and the Deseret of this report equivalent to the Pine Canyon of Tintic. The part of this correlation referring to the Deseret seems well supported by the paleontologic evidence, though, as suggested above, there is doubt that any of the Madison is to be correlated with the Pine Canyon. Wichman [80] suggested a correlation very similar to the one here offered except that he believed that the Buckhorn ore beds (the basal 30 feet of the Madison limestone as here defined) were not represented at Tintic. To the writer this appears to be a minor point, as there is doubt if any member so thin can be said (in the absence of tracing or definite fossil evidence) to per-

[73] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 60–61, 1927.

[74] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, p. 412, 1920.

[75] Calkins, F. C., Geology and ore deposits of the Cottonwood district, Utah: U. S. Geol. Survey report (in preparation).

[76] Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation).

[77] Loughlin, G. F., op. cit. (Prof. Paper 107), p. 40.

[78] Spurr, J. E., U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, pp. 375–377, 1895.

[79] Olmstead, S. G., op. cit., pp. 438, 441–442.

[80] Wichman, F. M., op. cit., p. 563.

sist for such a distance as separates Ophir and Tintic, and he is in practical agreement with Wichman on the classification of this part of the section.

The lowest Carboniferous of the San Francisco district is probably somewhat younger than Madison,[81] so that the time represented by the Madison limestone was probably one of nondeposition or even of erosion in that area. Carboniferous rocks occur in many of the other ranges of western Utah, and it is probable that the Madison is represented in several if not in all of them, but sufficient detailed work to prove its presence has not yet been done.

DESERET LIMESTONE (UPPER MISSISSIPPIAN)

Distribution and topographic expression.—The limestone here named Deseret limestone because of its exposures at the Deseret mine, in Dry Canyon, directly overlies the Madison limestone, and its distribution closely follows that of the Madison in both Ophir and Dry Canyons. However, it is also exposed south of Ophir Creek, in Mercur Canyon, which does not cut deeply enough to lay bare the Madison limestone. Its outcrop in Mercur Canyon is about a mile long and occurs close to the anticlinal axis. It plunges beneath the Humbug formation both up and down stream. Silverado Canyon has not cut deeply enough to expose the formation.

The Deseret, save for a thin, noticeably soft bench-forming shale at its base (a zone which is not exposed in Mercur Canyon), forms a fairly even steep surface, not so precipitous as that of the thick chert member of the Madison limestone, but somewhat steeper than the slopes of the thin-bedded limestones in the lower part of that formation.

Stratigraphy.—Except for the basal beds the Deseret limestone would be separable only with difficulty on lithologic criteria from the underlying Madison limestone. Like the Madison, it consists almost wholly of blue-gray fine-grained limestone with greater or less amounts of chert. The basal bed of the formation is a black shale, of some economic importance as marking the top of the zone of mineralization in the Hidden Treasure mine. It is immediately overlain by a thin bed of highly phosphatic oolite, the grains of which average perhaps 1 millimeter in diameter. Considerable numbers of broken and phosphatized fossil fragments also occur in this bed. There are a few sandy limestone and shaly layers above the basal shale, but these are rather thin with the exception of an 8-foot bed of quartzite which locally, near the Jim Fisk mine, occurs about 320 feet above the base. The following section is believed to represent the character of the formation in this district:

Section of Deseret limestone on north side of Ophir Creek

[West from a point about 200 feet north of the St. John & Ophir Railroad, west of the Cliff mine loading bins. Strike N. 40° W.; dip 38° SW.]

Humbug formation: Brown fine-grained 2-foot quartzite at the base.
Conformable contact.

Deseret limestone:	Feet
1. Dark-blue fine-grained limestone, with much black chert and some red-weathering shale. The chert nodules and lenses range from half an inch to 3 inches in thickness and occur at stratigraphic intervals of 2 to 3 inches near the base. The limestone contains large nodules of white calcite a quarter of an inch to 4 inches in diameter, distributed irregularly. Toward the top the member becomes more sandy, and sand beds 3 or 4 inches thick appear	131
2. Massive light-blue coarsely crystalline limestone, weathering light gray. Blocky, poorly bedded, very fossiliferous, carrying many crinoid stems, as well as other fossils	13
3. Thin-bedded limy, poorly laminated shale, carrying large amounts of chert	3
4. Limestone like bed 2	20
5. Massive-bedded blue limestone, not noticeably fossiliferous; weathers brown in patches owing to small amounts of irregularly distributed sand. Becomes more sandy and cherty upward	168½
6. Poorly exposed thin-bedded, somewhat sandy limestone	138
7. Massive, blocky sandy limestone; beds range from 8 inches to 3 feet in thickness and weather brown but are dark blue-gray on fresh fracture	30
8. Poorly exposed cherty blue limestone	137½
9. Poorly exposed black, red-weathering shale with a phosphatic oolite bed at the top	9
	650

Conformable contact.
Madison limestone, very cherty toward the top.

The upper boundary of the Deseret limestone is arbitrarily placed at the base of the first sandstone or quartzite bed of notable thickness. It is not a fixed stratigraphic horizon, for the quartzites and sandstones of the overlying Humbug formation are exceedingly lenticular and variable, so that the basal clastic bed at one locality is likely to be several tens of feet above the base only a few hundred yards away. Conversely, a sandstone or quartzite which is the lowest in one locality may be traced to its vanishing point, where the limestones of the Deseret are uninterrupted, possibly for as much as 50 feet higher stratigraphically. At best, the boundary is arbitrary, but it is believed that the distinction of the two units is decidedly important in connection both with historical geology and with structure determinations. The complex faulting of the Dry Canyon area is brought out most clearly by the displacement of this boundary.

[81] Girty, G. H., quoted by Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 36, 1913.

Age and correlation.—Fossils collected from the Deseret limestone during the course of this survey were submitted to G. H. Girty, who reports as follows:

From the Deseret limestone we have only one collection, 6256. It shows a marked faunal change from the preceding collections having a Madison fauna, but is itself more or less novel in facies. This fauna in some respects appears allied to the Moorefield fauna of Arkansas and Oklahoma, in others to the fauna of the White Pine shale of Nevada, which are mutually allied. In the Idaho section the fauna would find place in the lower part of the Brazer, and in the typical section of the Mississippi Valley somewhere in the middle Mississippian.

6256. About middle of Deseret limestone, north side of Ophir Creek, west of and above old tailing pond west of Ophir (Brazer); collected by G. H. Girty, Gordon New, and James Gilluly:

Triplophyllum sp.
Fenestella sp.
Lingula n. sp.
Schizophoria sp.
Productus ovatus.
Productus aff. P. altonensis.
Productus aff. P. sampsoni.
Pustula vittata.
Pustula hirsutiformis.
Pustula aff. P. moorefieldella var. pusilla.
Pustula, 3 sp. indet.
Camarotoechia sp.
Camarophoria thera?
Spirifer aff. S. moorefieldanus.
Spirifer aff. S. washingtonensis.
Spirifer sp.
Reticularia sp.
Brachythyris aff. B. suborbicularis.
Brachythyris sp.
Composita sp.
Cliothyridina aff. C. sublamellosa.
Pterinopecten n. sp.
Platyceras sp.

The shale that is taken as the base of the formation evidently marks a distinct change in the conditions of sedimentation represented by the highly cherty limestones below. The phosphatic oolite associated with the shale is also similar to material that has been elsewhere interpreted as marking disconformities in the stratigraphic column. There are no distinct members apparent between the phosphatic bed and the lowest fossils, which are of Brazer (upper Mississippian) affinities, and accordingly it seems very probable that the boundary between the upper and lower Mississippian occurs either immediately below or immediately above this shale, probably below.

As suggested in the discussion of the Madison limestone, it is possible that this shale should be correlated with the one at the top of the Gardner dolomite at Tintic, though this is by no means assured. If this correlation is correct, the rocks here named the Deseret limestone are the direct equivalents of those included by Loughlin in the Pine Canyon limestone at Tintic and that name could be transferred to Ophir without coining a new term. However, as reviewed above, Loughlin regarded the Pine Canyon (because of the cherty beds in the lower part) as probably in part of Madison age, whereas these rocks at Ophir are almost surely entirely of Brazer age. Even if the shales of the two sections are not equivalent, the Deseret must represent a partial correlative of the Pine Canyon, for the upper and only fossiliferous part of the Pine Canyon is of upper Mississippian (Brazer) age and both formations lie conformably beneath closely similar lenticular sequences of quartzite and limestone.

It is uncertain where Olmstead drew the boundaries for his Pine Canyon formation,[82] but apparently he included in it much of the group here considered Madison and followed no consistent usage in drawing the top of the unit, for in one place he speaks of the Hidden Treasure mine being in the upper member of the formation, whereas in another place he states that the upper member crops out in Mercur Canyon. The shale here considered the base of this formation is just above the Hidden Treasure ore bodies—hence in the usage of the writer the workings of that mine are not in the Deseret but in the Madison limestone. The Deseret as here defined, however, includes the strata in Mercur Canyon referred to the Pine Canyon by Olmstead. The Madison rocks in which the Hidden Treasure mine is situated do not crop out in Mercur Canyon. Wichman pointed out the Mississippian age of these rocks but did not suggest correlation with other areas.

The Deseret is the lowest formation included in the area studied by Spurr [83] around Mercur. He referred to it there as the "Lower Blue limestone" and cited a report by Charles Schuchert giving its age as "Lower Carboniferous."

The type locality of the Brazer limestone is in the Randolph quadrangle, Utah.[84] In that district the formation, which ranges in thickness from 800 to 1,400 feet, carries a phosphatic member in shaly beds near the base. Considerable cherty and sandy material is present higher in the formation, and in this respect it resembles the upper Mississippian of the Oquirrh Mountains considered as a whole. However, a precise correlation between the areas is at present impossible, though it seems likely that the Deseret corresponds to the lower part of the type Brazer. The Cottonwood Canyon section of the Wasatch Range [85] and that of the San Francisco district [86] resemble the Oquirrh section in general, but a discussion of regional correlations can hardly be profitable in the present state of our knowledge, because no faunal zones have yet been recognized as significant in the upper Mississippian rocks of the Rocky Mountain region.

HUMBUG FORMATION (UPPER MISSISSIPPIAN)

Distribution and topographic expression.—The Humbug formation is prominently exposed in Ophir Canyon, above the Deseret limestone. The outcrop west of the Cliff fault passes over the divide into Dry Canyon and, after being displaced in a complex man-

[82] Olmstead, S. G., op. cit., pp. 442–443.
[83] Spurr, J. E., op. cit., p. 371.
[84] Richardson, G. B., op. cit., p. 413.
[85] Calkins, F. C., op. cit., pp. 238–239.
[86] Butler, B. S., op. cit., pp. 35–36.

ner by several faults on the north side of Dry Canyon, passes above the Queen of the Hills mine and the Surprise (Garber) tunnel and thence down the west flank of Bald Mountain to the mountain front. South of Ophir Creek it is exposed on Lion Hill, in the westward-facing saddle between Lion Hill and Chloride Point, and in Silverado Canyon, West Dip Canyon, and Mercur Canyon. South of Mercur Canyon the formation crops out in an irregular area as far south as McFait Canyon, beyond which it is represented by very small exposures in the bottom of Mitchell Canyon and its northern tributary.

On the east flank of the range the Humbug is the lowest formation exposed on the axis of the Long Ridge anticline. It crops out over the southern tip of Long Ridge from the alluvium boundary nearly to the 6,500-foot contour, a distance along the ridge of about 1½ miles.

Over all its area of exposure the formation, owing to the alternation of sandstones (or quartzites) and limestones of which it is composed, has a tendency to develop a ledge and slope topography only slightly more irregular than that of the limestones between which it lies but conspicuous because of the brown-weathering sandstones and quartzites whose float masks to a considerable extent the really considerable portion of limestone in the formation.

Stratigraphy.—The lower boundary of the Humbug formation is arbitrarily placed at the base of the lowest considerable quartzite or sandstone in the Mississippian section. The sandstones (or quartzites) are lenticular, so that the lowest sandstone in a given section when followed along the outcrop is found to lens out, leaving a sandstone that in the given section was locally some feet higher as the lowest sandstone in the new section; or another lens may appear below, so that a new base must be selected for the formation. Similar relations exist at the top of the formation, and it is fairly certain that exactly the same time unit is not represented by this formation at different localities. Nevertheless, the wide distribution of an interfingering series of upper Mississippian sandstone and limestone in Utah makes it seem probable that no very great time differences are involved.

The following section represents the general character of the formation, though it is quite certain that another section measured only a few feet away would differ considerably.

Section of Humbug formation on north wall of Ophir Canyon, on south slope of Dry Mountain, 300 to 400 feet above Ophir Creek

[Strike N. 40° W.; dip 45° SW.]

"Great Blue" limestone: Dark blue-gray limestone, weathering light gray.

Conformable contact.

Humbug formation:	Feet
1. Interbedded blue-gray fossiliferous limestones and sandstones as much as 2 feet thick	12½
Humbug formation—Continued.	
2. Light blue-gray fossiliferous limestones	17½
3. Brown even-grained sandstone	4½
4. Dark blue-gray limestone	3
5. Brown sandstone	6½
6. Blue-gray coarsely crystalline fossiliferous limestone	11
7. Poorly exposed brown limy sandstone	13
8. Poorly exposed limestones and sandstones, alternating in beds as much as 1 foot thick	34
9. Buff sandstone	1
10. Gray limestone	8½
11. Platy, thin-bedded brown quartzite	11½
12. Gray limestone with white blotches of calcite, fossiliferous	25
13. Quartzite with some interbedded thin limestone	11½
14. Limestone in beds that average about 2 feet thick	11
15. Brown quartzite	3
16. Gray crystalline fossiliferous limestone	9½
17. Brown quartzite	4
18. Shaly gray limestone	4
19. Brown quartzite	5½
20. Thick-bedded light-gray fossiliferous crystalline limestone carrying white blotches of calcite	15
21. Brown quartzite	6
22. Gray limestone in beds 2 to 4 feet thick, containing a few small lenses of quartzite	20½
23. Irregular quartzite lens; disappears within a few feet to the south but increases to the north	2
24. Blue-gray limestone	7½
25. Massive brown quartzite	5½
26. Gray limestone	2
27. Gray, brown-weathering blocky quartzite	24
28. White calcite breccia, containing fragments of bluish-gray limestone and stringers of sand. Very persistent and can be followed long distances	5½
29. Light-brownish quartzite	12½
30. Breccia zone like bed 28	7½
31. Light-gray sandy limestone, carrying small lenses of brownish-weathering quartzite	9½
32. Brown quartzite	7
33. Blue-gray limestone	24
34. Brown quartzite	7½
35. Dense blue-gray limestone, in one bed	33
36. Concealed; probably chiefly limestone	50½
37. Coarsely crystalline fossiliferous blue-gray limestone	11½
38. Gray, buff-weathering quartzite	3
39. Coarsely crystalline blue-gray limestone	14½
40. Gray, brown-weathering quartzite, in beds from 1 inch to 2 feet thick	37
41. Poorly exposed alternating thin limestones and quartzites	30
42. Limy gray sandstone varying to sandy limestone	12
43. Blocky, poorly bedded brown sandy shale	1
44. Dense irregular lenticular blue limestone	1
45. Brown limy sandstone	7
46. Gray sandy limestone	11
47. Fine-grained blocky, evenly bedded quartzite in layers 1 to 18 inches thick; highly silicified and weathers dark brown	7½

Humbug formation—Continued.	Feet
48. Sandy limestone varying to limy sandstone both along and across the bedding; weathers brownish gray and breaks into blocks. The beds range between 1 and 3 feet in average thickness and lens in and out	72
49. Brown fine-grained quartzite	2
Conformable contact.	645½

Deseret limestone: Dark-blue cherty limestones without sandstone beds, except very locally.

Sandstones and quartzites make up roughly 30 per cent of the above section, and in this respect the section is probably typical of the formation. The general absence of finer clastic material is striking, in view of the numerous alternations of limestone and coarser clastic rocks.

The field discrimination between sandstone and quartzite was made on the basis of scratching tests with the geologic pick. It is probable that few of the beds designated quartzite are cemented throughout with silica, but certainly many of them are in large part so cemented. To a certain extent this may be a surficial phenomenon connected with weathering, but much of it is assuredly not of this origin.

Microscopic examination shows that the sandstones are composed of subrounded grains of quartz with subordinate amounts of microcline and plagioclase. The grain size of the specimens studied was very uniform, ranging between about 0.2 and 0.3 millimeter in diameter. In the specimens examined microscopically, calcite cement was predominant over silica.

The variations in the Humbug (Spurr's "Lower Intercalated series") from place to place were noted by Spurr,[87] who measured two sections about three-quarters of a mile apart. One of these was considerably greater than the other, the beds of sandstone being thicker and more numerous and separated by thicker limestone beds. One section had 19 beds of sandstone, the other only 14, and the lensing out of individual beds was observed in the field. The thickness (120 feet) of one of the sandstones he measured is much greater than that of any measured by the writer and still further illustrates the lateral lensing of the beds.

Age and correlation.—Fossils collected from the Humbug in Ophir Canyon were referred to G. H. Girty for study. His report is as follows:

> The Humbug formation has given us two collections, 5800 and 6257. The fauna is a rather small one, and its closest affinities are with the earlier faunas of the Brazer limestone.
>
> 5800. Humbug formation, north side of Ophir Canyon, about 1½ miles below Ophir, Utah; collected by Sidney Paige:
>
> Fenestella, several sp.
> Pinnatopora sp.
> Polypora sp.
> Rhombopora sp.
> Orthotetes? sp.
> Productus brazerianus.
> Girtyella? sp.
> Spirifer aff. S. centronatus.
>
> 6257. From lower 200 feet of the Humbug formation, north side of Ophir Canyon, west of Ophir; collected by G. H. Girty and James Gilluly:
>
> Syringopora sp.
> Cyathophyllum sp.
> Pentremites sp.
> Crinoid indet.
> Echinocrinus sp.
> Productus brazerianus.
> Productus ovatus?
> Productus sp.
> Pugnoides aff. P. ottumwa.
> Spirifer n. sp. aff. S. breckenridgensis.

Regional correlation of the Humbug formation, in view of its considerable local variations, would seem rather dubious, yet it seems not unreasonable to extend the usage of the name to this area from Tintic, where the formation was established.[88] This correlation is based partly on the age determination from fossil evidence and partly on the remarkable lithologic similarity of the two sections, not in details, which differ very greatly, but in the larger features, such as the presence of interlensing brown quartzite, brown and reddish sandstones, and blue and gray limestones, with a very little shale. It is probable that the base of the formation as delimited at Ophir is not at the exact horizon of the base at Mercur and that both of these differ from the base at Tintic, but the fairly comparable pre-Humbug Mississippian sections of 1,100 feet at Ophir and an uncertain total of about 1,500 feet at Tintic seem to point to their essentially similar stratigraphic relations being due to a close age equivalence. This correlation has been previously suggested by Olmstead [89] and seems strengthened by the presence of similar lithology in the Mississippian at so distant a locality as Gold Hill,[90] in the Deep Creek Range, Utah. At Gold Hill, however, there is very little limestone of post-Madison age beneath these rocks, and they may represent a somewhat greater age than the Humbug, though the fact that they overlap the Madison and locally rest on Devonian may indicate that there was a considerable post-Madison time interval before their deposition. Loughlin [91] reports lithologically similar rocks of upper Mississippian age in the Lake Mountains, just east of the Fairfield quadrangle. Interbedded limestones and quartzites in the Cottonwood quadrangle seem also closely comparable. Deposits so similar and unusual at localities so widely separated seem likely to represent a unit of deposition. It seems highly probable that the Humbug is equivalent to a part of the type Brazer—what part, however, it will require tracing through intervening areas to determine.

Conditions of deposition.—The presence of such a series of clastic rocks as the quartzites of the Humbug formation undoubtedly connotes their origin in localities accessible to considerable currents. Yet the fine

[87] Spurr, J. E., op. cit., pp. 372–374.

[88] Tower, G. W., and Smith, G. O., The geology and mining industry of the Tintic district, Utah: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 626, 1899.

[89] Olmstead, S. G., op. cit., p. 443.

[90] Nolan, T. B., op. cit.

[91] Loughlin, G. F., op. cit. (Prof. Paper 107), p. 42.

limestones, which rest directly upon the quartzites and interfinger with them, must have required, it would seem, a depositional environment free from powerful currents. Apparently the conditions demanded are those of alternating periods of active currents and calm, and for this reason the totally insignificant quantity of silt in the formation is very striking and may indicate that the sediments were supplied by the erosion of a terrane consisting dominantly of quartzose and limy sediments, and probably not from an igneous, metamorphic, or shaly land mass.

"GREAT BLUE" LIMESTONE (UPPER MISSISSIPPIAN)

Distribution and topographic expression.—Above the Humbug formation is the "Great Blue" limestone, which crops out over most of the southwestern part of the Oquirrh Mountains. South and southwest of Soldier Creek and Manning Canyon most of the mountain area is covered by this great limestone. Only in the canyons are older formations exposed. Its area of outcrop in this part of the range exceeds 33 square miles.

The formation is likewise exposed on the east flank of the range, where it is brought to the surface by the Long Ridge anticline. This eastern outcrop covers an area of 5 or 6 square miles, from Iron Canyon on the north to the alluvium south of Bald Knoll. Another exposure, believed to represent this formation, occurs in the extreme southwest corner of the Stockton quadrangle, in the foothills of the Stansbury Range. Over most of its outcrop the "Great Blue" limestone forms slopes that are considerably less rugged than those of the Humbug formation below and the Oquirrh formation above, though here and there it makes ledges of considerable height.

Stratigraphy.—The "Great Blue" limestone rests conformably on the Humbug formation, the boundary, which is purely arbitrary, being placed at the top of the highest considerable group of sandstone beds. Sandstones occur higher in the section, in the lower 1,000 feet of the "Great Blue," but these are sporadic individual lenses, and the boundary is placed to mark the practical cessation of notable sandy deposition.

The "Great Blue" limestone consists of a lower and an upper limestone, separated by shaly beds herein named the Long Trail shale member. The lower limestone member, between the top of the Humbug and the base of the Long Trail shale, is, according to the mean of four measurements, about 500 feet thick. The thickness as given by Spurr [92] is about twice this figure, but the four measurements by the writer agreed within 100 feet, and although exposures are not sufficiently complete to make this thickness certainly correct, some confidence is felt that this approximation is fairly close to the truth.

[92] Spurr, J. E., op. cit., p. 375.

Because of its close association with the great ore bodies of Mercur and with the ores of the Mono mine, in Dry Canyon, as well as its value as a stratigraphic marker, the black carbonaceous shale that separates the thick limestones of the "Great Blue" has been mapped as a distinct member. The name Long Trail shale member is herein applied to it because of its excellent exposure at the head of Long Trail Gulch, in Ophir Canyon. Elsewhere this shale is very poorly exposed, as it weathers much more readily than the limestones between which it lies. The only thoroughly satisfactory exposure of the unit throughout its extent is that at the head of Long Trail Gulch, where it is about 85 feet thick. Elsewhere it appears to be much thinner, but its topographic importance as a valley maker is so great that the measurement is thought to be fairly representative of the member throughout the area.

Overlying the Long Trail shale is the upper limestone member of the "Great Blue" limestone, consisting of blue-gray limestone like that beneath the shale and containing sporadic chert layers, some sandy limestone, and a very subordinate quantity of black shale. This upper limestone member was measured at three places. A measurement east from the head of Silverado Canyon gave 2,400 feet; one at Mercur gave nearly 3,100 feet; and the third, on Bald Knoll, on the eastern flank of the range, yielded a figure very nearly the mean of these—2,725 feet. It is practically certain that no real changes so great as these occur in the thickness of the "Great Blue" within distances so short, and the differences are almost surely due to errors in measurement. These errors are doubtless due to variable dips in the limestone, the changes in which are difficult to evaluate.

If the mean of the three measurements is rounded off at 2,750 feet and used as the most probable thickness of the upper limestone member of the "Great Blue," the total thickness of that formation is about 3,600 feet. The total thickness of the "Great Blue" limestone, if the "upper shale" of Spurr [93] (the Manning Canyon shale of the present report) is taken as its upper limit, is given by Spurr as 3,525 feet, a fair agreement in total, despite the discrepancy between his measurement of the thickness of the lower limestone member and that of the present report.

Other than the Long Trail shale member, no good marker beds were discovered in the "Great Blue" limestone: it is a monotonous thick series of limestones throughout. In local areas, as at Mercur, individual thinner beds, mostly shales, were recognized in the formation, and it is probable that similar distinctive members could be determined in many other parts of the quadrangles, but such distinctions must rest upon much more detailed work than was possible in this survey.

[93] Spurr, J. E., op. cit., p. 375.

Age and correlation.—The "Great Blue" limestone was named by Spurr from its exposures in the Mercur district. The name has become so firmly established among the mining men of Utah that its retention seems best, despite the fact that it indicates no definite type locality and has no geographic significance. The fossils collected from the lower part of the formation by Spurr were determined by Schuchert to be lower Carboniferous (Mississippian). The upper part was considered probably upper Carboniferous (Pennsylvanian). Fossils collected from the "Great Blue" limestones during the present survey have been examined by G. H. Girty, who reports as follows:

From the "Great Blue" limestone we have three collections definitely located stratigraphically—lot 6018, from the lower part, below the Long Trail shale member; lot 6020, from the Long Trail itself; and lot 6258, from about 1,000 feet above the Long Trail shale. The fauna of lot 6018 is not especially distinctive, but I should group it with the preceding faunas and assign it on broad lines to the lower part of the Brazer limestone and the middle part of the typical Mississippian. The fauna of lot 6020 is sui generis by reason especially of the large pelecypod representation, though naturally most of the species are related to species that we know already. This fauna is in marked contrast to those that preceded it and also to those that followed it, without suggesting a great difference in geologic age. Tentatively it may be referred to the lower Brazer and to the middle Mississippian. The fauna of lot 6258 is small and the specimens not well preserved. It carries suggestions of a younger facies than the preceding faunas but has nothing decisive. Provisionally this lot may be grouped with those already considered.

It remains to discuss a few lots whose stratigraphic relations were not obvious in the field. These are 6264, 6264a, 6267, 6270, and 6272.

Lot 6270 is remarkable in several ways, especially in containing numerous *Pentremites*, though unfortunately these fossils occur in such a condition that they can not be identified specifically. Tentatively the age may be placed at high middle or upper Mississippian. Nothing in the Mississippian collections just discussed shows the same peculiar feature, however. Another fauna of striking individuality is represented by lots 6264 and 6264a, which probably represent about the same horizon and fauna. Nothing closely comparable to this fauna is found in any of the other collections, whether of Mississippian or Pennsylvanian age, and their geologic age must be given in a very qualified way, inasmuch as it rests on very general relations. Tentatively the age may be set down as upper Mississippian, though it is not specifically related to any of the typical Mississippian faunas nor closely allied to any of those called Mississippian in the same area, in the Gold Hill area, or in the Brazer of Idaho, although this assignment would of necessity make it Brazer. It is to be borne in mind, however, that this fauna is much larger and more varied than most of the Mississippian faunas from the Oquirrh Mountains and that some of the other collections might be of the same age as this and contain a few of the same species without showing a resemblance that was very obvious or that could be relied on for correlation. Lot 6272 appears to be Mississippian also, judged by its general character, yet it has no counterpart in the other Mississippian fauna of this area nor yet in the Gold Hill area; still less in the typical Mississippian faunas of the Middle West. The evidence on which it is assigned may be unreliable in view of the new values in range that certain types appear to hold in the faunas of western Utah.

Collection 6267, on the paleontologic evidence, definitely belongs in the Brazer.

6018. Limestone low in "Great Blue," just east of Lakes of Killarney fault, 6,400-foot contour, between Ophir and Dry Canyons, Stockton quadrangle; collected by James Gilluly:

Echinocrinus sp.
Fenestella sp.
Chonetes capax?
Productus ovatus.
Avonia sp.
Productus richardsi?
Pugnoides aff. P. ottumwa.
Girtyella indianensis?
Spirifer n. sp. aff. S. pellensis.
Composita trinuclea.
Cliothyridina sublamellosa.
Myalina sp.

6020. From Long Trail shale at mouth of prospect tunnel on south side of Ophir Canyon opposite baseball grounds; collected by Edwin Kirk and M. J. Buerger:

Fenestella several sp.
Cystodictya aff. C. lineata.
Rhombopora sp.
Lingula aff. L. varsoviensis.
Lingulidiscina sp.
Chonetes aff. C. oklahomensis.
Productus ovatus.
Productus semireticulatus.
Pustula aff. P. vittata.
Avonia aff. A. arkansana.
Camarotoechia aff. C. purduei var. agrestis.
Pugnoides aff. P. ottumwa.
Spirifer aff. S. pellensis.
Composita aff. C. trinuclea.
Cliothyridina sublamellosa.
Cardiomorpha? sp.
Sphenotus aff. S. vulgaris.
Allerisma? sp.
Yoldia aff. Y. multistriata.
Leda aff. L. stevensiana.
Schizodus sp.
Posidonomya fragosa?
Myalina arkansana?
Myalina aff. M. keokuk.
Myalina sp.
Aviculipecten aff. A. tahlequahensis.
Aviculipecten aff. A. talboti.
Aviculipecten sp.
Aclisina? sp.

6258. "Great Blue" limestone, about 1,000 feet stratigraphically above the Long Trail shale member, west of road to Gisborn, just above alluvium; collected by G. H. Girty, Gordon New, and James Gilluly:

Stenopora sp.
Batostomella sp.
Fenestella sp.
Rhombopora sp.
Schizophoria? sp.
Orthotetes aff. O. kaskasiensis.
Chonetes aff. C. levis.
Productus ovatus.
Productus aff. P. inflatus.
Productus aff. P. parvus.
Diphragmus? sp.
Composita sp.

6264. From fault block west of Lakes of Killarney fault, just north of Dry Canyon; possibly contaminated by float, but probably not; collected by G. H. Girty and James Gilluly:

Triplophyllum sp.
Stenopora aff. S. ramosa.
Stenopora sp.
Anisotrypa sp.
Fenestella several sp.
Polypora sp.
Rhombopora sp.
Chonetes aff. C. oklahomensis.
Productus ovatus.
Productus ovatus var. minor.
Productus aff. P. richardsi.
Productus aff. P. parvus.
Productus semireticulatus.
Productus aff. P. inflatus.
Productus aff. P. gallatinensis.
Productus aff. P. viminalis.
Avonia aff. A. arkansana.
Avonia sp.
Pustula sp.
Pustula n. sp. aff. P. biseriata.
Pustula sp.
Pustula? sp.
Camarophoria aff. C. explanata.
Dielasma aff. D. formosum.
Spirifer aff. S. arkansanus.
Spirifer aff. S. missouriensis.
Spirifer aff. S. leidyi.
Spiriferina spinosa.
Reticularia setigera?
Ambocoelia sp.
Composita aff. C. subquadrata.
Cliothyridina sublamellosa.
Naticopsis sp.
Griffithides sp.

6264a. Same locality as 6264, from bedrock:

Campophyllum torquium.
Stenopora sp.
Orthotetes aff. O. kaskaskiensis.
Productus aff. P. coloradoensis.
Productus ovatus.
Composita aff. C. subquadrata.
Cliothyridina sublamellosa.
Griffithides sp.

6267. From "Great Blue" limestone at extreme southwest corner of Stockton quadrangle, from foothills of Stansbury Range; collected by G. H. Girty:

Clisiophyllum? sp.
Orthotetes? sp.
Productus brazerianus.
Deltopecten? sp.

6270. From foothills of Oquirrh Mountains, south of Dry Canyon, west of Lakes of Killarney fault, near Lakes of Killarney mine; collected by James Gilluly:

Triplophyllum sp.
Pentremites sp.
Echinocrinus sp.
Crinoidal fragments.
Glyptopora sp.
Fenestella sp.
Polypora sp.
Schizophoria n. sp.
Productus aff. P. gallatinensis.
Diaphragmus elegans?
Spirifer aff. S. pellensis.
Spiriferina spinosa.
Composita aff. C. trinuclea.
Cliothyridina sublamellosa.

6272. Bald Knob, Fairfield quadrangle, "Great Blue" limestone; collected by James Gilluly and W. D. Mark:

Triplophyllum sp.
Stenopora sp.
Orthotetes? sp.
Chonetes aff. C. levis?
Productus ovatus.
Productus aff. P. gallatinensis.
Avonia? sp.
Spirifer aff. S. leidyi.
Spiriferina spinosa.
Eumetria verneuiliana.
Composita subquadrata.
Cliothyridina sublamellosa.
Cardimorpha? sp.
Nucula aff. N. subrotundata.
Schizodus sp.
Conocardium sp.
Streblopteria tenuilineata?
Astartella sp.
Bellerophon aff. B. sublevis.
Euphemus sp.
Pleurotomaria 2 sp.
Goniospira? sp.
Holopea aff. H. proutana.
Diaphorostoma aff. D. peoriense.
Bulimorpha aff. B. inornata.
Straparollus aff. S. subumbilicatus.
Aclisina sp.
Griffithides sp.

The upper Mississippian age of the "Great Blue" limestone is seen to be firmly established. Doubtless it finds its correlatives in the limestones of this age that immediately succeed the Humbug type of sediments in adjacent portions of Utah. In the present state of our knowledge detailed correlations with other areas are almost impossible, owing to the absence of recognizable fossil zones in the upper Mississippian of the Rocky Mountains. However, it seems pertinent to point out the similarity between the "Great Blue" limestone of the Oquirrh Mountains and the Ochre Mountain limestone [94] of the Deep Creek Range, each consisting of a great thickness of limestones with an intercalated shale member and each conformably overlying the Humbug formation. Each formation is upper Mississippian and is followed by black shales and quartzites within which occurs the Pennsylvanian-Mississippian boundary. Possible correlatives of the "Great Blue" limestone may exist in the Cottonwood district,[95] the San Francisco district,[96] and the Randolph quadrangle [97] and adjacent parts of Idaho,[98] inasmuch as the upper Mississippian is represented in those areas, but the lithologic similarities are apparently slight, and it hardly seems profitable to discuss the question in the absence of more definite faunal zones than have been so far recognized in this region.[99]

[94] Nolan, T. B., Paleozoic formations in the Gold Hill quadrangle, Utah: Washington Acad. Sci. Jour., vol. 20, pp. 430–431, 1930.

MISSISSIPPIAN AND PENNSYLVANIAN SERIES

MANNING CANYON SHALE

Distribution and topographic expression.—The formation here named the Manning Canyon shale crops out in a rather narrow band from Manning Canyon on the southeast over the divide to the valley of the south fork of Ophir Creek. Its outcrop follows the east side of the valley of the south fork into Ophir Canyon, which it crosses about half a mile above the forks. Here its position is somewhat doubtful owing to brush cover and slide rock, but after some displacement by faulting the outcrop trends northwestward, up the north side of Ophir Canyon, and thence down the south fork of Soldier Creek. The outcrop swings westward and determines the main valley of Soldier Creek to a point within a mile of its mouth but here diverges from the creek and climbs the north wall of the canyon. Just north of the canyon mouth it is cut off by a rather large fault of the Basin Range system.

Several small outcrops interpreted to belong to this formation occur in the low foothills on the west flank of the range near the Lakes of Killarney mine, between Dry and Ophir Creeks, and others occur just south of Ophir Creek across from the Bates ranch. On the eastern slope of the range the Manning Canyon shale crops out in a northwestward-trending belt from Threemile Canyon to the head of Iron Canyon, where it swings sharply east and then southeast. Exposures are very poor farther southeast, but it seems very probable that the main valley of West Canyon below Iron Canyon is in part determined by the presence of this soft, easily eroded shale. However, other factors are involved, and it is possible that the formation is faulted out and does not determine the lower course of West Canyon.

Throughout its area the Manning Canyon shale is a valley-forming formation, and because it is relatively impervious to water it gives rise to numerous springs. Owing to these springs the vegetation is much more flourishing on this shale than on the other formations, and exposures are very poor. Structural

[95] Calkins, F. C., op. cit. (Prof. Paper 111), pp. 238–239.
[96] Butler, B. S., op. cit. (Prof. Paper 80), p. 29.
[97] Richardson, G. B., op. cit., pp. 413, 414.
[98] Girty, G. H., in Mansfield, G. R., op. cit., pp. 63–71.
[99] For a discussion of the unsatisfactory character and distribution of the Brazer fauna, see Girty, G. H., idem.

and stratigraphic details respecting the formation are accordingly very difficult to obtain.

Stratigraphy.—The lower boundary of the Manning Canyon shale is exposed in only a very few places within the Stockton and Fairfield quadrangles. Perhaps the clearest exposure is that on the north side of Soldier Canyon about a quarter to half a mile above the mouth. In this locality the "Great Blue" limestone becomes more shaly toward the top and by interbedding of limestone and shale, with increasing quantities of shale, passes by gradation into the dominantly shale unit, the Manning Canyon shale. The gradation occurs through a series of beds about 200 to 300 feet thick.

Because of the position of the Manning Canyon shale between two very thick and strong formations, it has been decidedly squeezed and deformed by the forces that folded the strata, the contortion and differential thinning being so great that it is doubtful whether a section measured at any place in the quadrangles can be considered accurate within about 30 per cent. Nevertheless, four nearly complete sections and several partial sections were measured, but, as was expected, they yielded very inconsistent figures for the thickness of the formation. The results of the four measurements are as follows: At the saddle west of Lewiston Peak (top uncertain within 200 feet), 750 feet; south side of Hall Canyon (base not exposed), 980 feet; north side of Hall Canyon (base not exposed), 1,140 feet; near mouth of Soldier Creek, 1,140 feet. Probably the last measurement is the most reliable, but it must be considered only a rough approximation to the thickness of the formation where it is undisturbed. These differences in the measured thickness may indicate either lateral depositional thinning or an erosional unconformity within the formation, but inasmuch as the strata measured are all disturbed and squeezed, there is doubt as to the differences having any real stratigraphic significance; they may all be due to differential compaction during the folding. It is believed that an assumption of an unconformity within the formation would be, on the evidence at hand, gratuitous, although Hintze [1] reports one at this horizon in the Wasatch Range.

The section measured in Soldier Canyon is believed to represent the formation better than any of the others, and although none of the members could be traced or recognized over any considerable distances along the strike, it is given in some detail in order to furnish data for the discussion of the fossil evidence regarding the boundary between the upper Mississippian and the Pennsylvanian which occurs within the formation.

[1] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 115–120, 1913.

Section of Manning Canyon shale measured on north side of Soldier Canyon about half a mile above its mouth

	Feet
Oquirrh formation: Limestone, in beds as much as 1 foot thick, carrying plentiful fossils. (See collection 6266a, made about 300 feet stratigraphically above the base.)	
Conformable contact.	
Manning Canyon shale:	
1. Limy shale and shaly limestone, interbedded, carrying a fauna represented by collections 6260 and 6266 in a limestone bed about the middle of the member	185
2. Dark shale, with a few thin limestones interbedded	235
3. Thick-bedded gray limestones, forming a ledge	32
4. Black shale, without fossils	78
5. Thin-bedded limestone carrying fossils represented by collections 6259, 6265, and 6265a	1
6. Dark-gray carbonaceous shale, unfossiliferous	150
7. Brown-weathering quartzite, forming a ledge	4
8. Dark-gray shale	147
9. Gray limestone, in beds about 2 feet thick	12
10. Chiefly shale, with some interbedded limestone	35
11. Limestone, in beds about 2 inches thick	17
12. Carbonaceous shale	43
13. Limestone like bed 11, carrying fossils	40
14. Carbonaceous shale	78
15. Limestone, like bed 11	8
16. Concealed, probably chiefly shale, but with some limestone	75
	1,140
Conformable contact.	
"Great Blue" limestone: Shaly limestone interbedded with less shaly material, the shale decreasing in abundance downward.	

At several localities quartzite beds with thicknesses as great as 40 feet were seen in the formation. These beds appear to be very lenticular, however, and though found in nearly every section which is at all well exposed, they can not be traced for any considerable distance.

As noted in the section given above, the upper contact of the Manning Canyon shale is, like the lower contact, conformable, and the transition to the adjacent formations both above and below is a gradual one. If any unconformity is associated with the formation, it must lie within it. The lithology of the formation represents deposition in much shallower waters than those in which the formations above and below it were laid down, but no evidence was discovered that shows that the region was emergent at any time during the interval, although it may have been.

Age and correlation.—Abundant fossils were obtained from this formation during the survey by G. H. Girty and the writer. Mr. Girty's study of the collections, a report of which is given below, showed that the Manning Canyon shale is in part upper Mississippian and in part Pennsylvanian. It was first thought that the quartzite (No. 7) of the section in Soldier Canyon marked the base of the Pennsylvanian.

This supposition was, however, proved erroneous by the work of Mr. Girty, who discovered in several localities, including the one described above, typical Chester (upper Mississippian) fossils at horizons above the lowest quartzite beds of the formation. It is true that in one locality, not far from the place where the section was measured, a quartzite member occurs between the highest Mississippian and lowest Pennsylvanian fossils found, but this quartzite is not the lowest in the section, an even more prominent one beneath it at the same locality being succeeded by fossiliferous limestones of Chester age. Owing to the poor exposures and absence of distinctive beds it proved impossible to distinguish the Pennsylvanian and Mississippian portions of the formation in mapping; the accompanying geologic map accordingly shows the distribution of the lithologic (not time) unit.

The Manning Canyon shale is the "upper shale" of Spurr's "Great Blue" limestone.[2] The thickness, reported by him "somewhat more than 100 feet," is much too small, but the error is due to the very poor exposures in the area which he studied.

Similar lithology is found in the Manning Canyon formation of the Gold Hill quadrangle, Utah,[3] where the formation likewise includes the lowest Pennsylvanian rocks and may possibly contain some upper Mississippian rocks. No other comparable beds in this stratigraphic position have yet been described from Utah, so far as the writer is aware.

Mr. Girty's discussion of the fossil collections is as follows:

> Five collections were made in the Manning Canyon shale—lots 6259, 6260, 6265, 6265a, and 6266. Lot 6265 contains little that is distinctive, but it is interesting inasmuch as the pelecypod representation strikingly recalls that of the Long Trail shale (lot 6020). Lot 6265a, from about the same locality and horizon, does not contain those pelecypod species but does contain other forms that indicate an upper Mississippian and upper Brazer age. The same is true also of lot 6259. I should remark, however, that the upper Brazer fauna in its integrity has not been found in the Oquirrh Mountains, and the Oquirrh faunas are called upper Brazer less because they agree exactly with the typical upper Brazer and more because they appear to be correlative, like the typical upper Brazer, with the Chester faunas of the Mississippi Valley. Even in Idaho the terms upper Brazer and lower Brazer do not imply as a rule any definite boundaries. We know only that certain collections are stratigraphically lower and paleontologically older, in appearance at least, than others. No sharp distinction can at present be made either in the faunas of the Oquirrh Mountains, and from these facts it would follow that the boundary between upper Brazer and lower Brazer may not be taken at the same horizon in the two areas.
>
> Collections 6260 and 6266 came from the upper half of the Manning Canyon shale and are of Pennsylvanian age. Inasmuch as this fauna immediately follows one of Chester age, it should contain (and probably does) beds that can be correlated with the Pottsville, but as the Pottsville faunas of the West would presumably differ materially from the Pottsville faunas of the East, and as the Pottsville deposits of the East are either nonmarine or contain faunas only partly described, the problem here is a rather delicate one. In the Gold Hill district there occurs a series of beds which I at first believed to be upper Mississippian but which later with Mr. Nolan's help I decided to correlate with the Pottsville. The Pottsville faunas of the Gold Hill area, though not very varied, were abundant and well preserved. The same facies is poorly represented in the collections from the Oquirrh Mountains, though I seem to recognize it there, especially in lots 6260 and 6266. Other lots (notably 6266a, b, and c, collected low in the overlying Oquirrh formation) probably belong in the Pottsville also and quite possibly still others, but their discussion will be included with that of the other collections from that formation, it merely being pointed out here that there is no marked faunal change at the top of the Manning Canyon shale. The boundary between the Mississippian and Pennsylvanian series occurs within the Manning Canyon shale.
>
> 6259. Shale just below the horizon of a second quartzite along the strike in the Manning Canyon, north side of Soldier Canyon, about a quarter of a mile above mouth (Chester); collected by G. H. Girty, James Gilluly, and Gordon New:
>
> Stenopora sp.
> Meekopora sp.
> Septopora sp.
> Schizophoria n. sp.
> Orthotetes aff. O. kaskaskiensis.
> Diaphragmus elegans.
> Diaphragmus elegans var.
> Pustula sp.
> Avonia aff. A. arkansana.
> Dielasma aff. D. chouteauense.
> Spirifer aff. S. pellensis.
> Cliothyridina sublamellosa.
> Griffithides sp.
>
> 6260. From limestone about 300 feet above the middle quartzite of the Manning Canyon shale, north side of Soldier Canyon, about a quarter of a mile above mouth (Pennsylvanian); collected by G. H. Girty, James Gilluly, and Gordon New:
>
> Hederella n. sp.
> Stenopora sp.
> Fenestella sp.
> Cystodictya aff. C. anisopora.
> Orthotetes sp.
> Productus semireticulatus.
> Productus aff. P. gallatinensis.
> Productus ovatus var. minor.
> Avonia aff. A. arkansana var. multilirata.
> Pustula aff. P. semipunctata.
> Pugnoides aff. P. ottumwa.
> Spirifer opimus var. occidentalis?
> Spiriferina spinosa var.
> Spiriferina sp.
> Composita subtilita.
> Cliothyridina orbicularis.
> Aviculipecten n. sp.
> Pleurophorus sp.
> Euphemus? sp.
>
> 6265. From shales of Manning Canyon shale on north side of Soldier Creek about half a mile above canyon mouth, below middle quartzite; same horizon as collection 6259; collected by G. H. Girty, James Gilluly, and Gordon New:
>
> Avonia aff. A. arkansana.
> Diaphragmus elegans?
> Pustula aff. P. punctata.
> Pustula sp.
> Dielasma sp.
> Spirifer aff. S. increbescens.
> Spiriferina sp.
> Ambocoelia? sp.
> Cliothyridina sublamellosa.
> Cliothyridina sp.
> Sphenotus aff. S. vulgaris.
> Cardiomorpha? sp.
> Leptodesma sp.
> Myalina aff. M. monroensis.
>
> 6265a. Same as 6265:
>
> Triplophyllum sp.
> Meekopora sp.
> Orthotetes aff. O. kaskaskiensis.
> Chonetes aff. C. levis.
> Productus brazerianus.
> Diaphragmus elegans.
> Avonia aff. A. arkansana.
> Spirifer aff. S. increbescens.
> Reticularia setigera.

[2] Spurr, J. E., op. cit., p. 375.
[3] Nolan, T. B., op. cit.

Spiriferina spinosa.	Leptodesma sp.
Composita subquadrata.	Sulcatipinna aff. S. missouriensis.
Cliothyridina hirsuta?	

6266. From limestone in upper 200 feet of Manning Canyon shale, probably same horizon as collection 6260, north side of Soldier Canyon, about half a mile above canyon mouth (Pennsylvanian); collected by G. H. Girty, James Gilluly, and Gordon New:

Lingula sp.	Productus ovatus var. minor.
Chonetes sp.	Avonia aff. A. arkansana.
Pustula sp.	Myalina perniformis?

PENNSYLVANIAN SERIES

OQUIRRH FORMATION

Distribution and topographic expression.—By far the thickest stratigraphic unit in the Oquirrh Mountains is the great mass of alternating limestones and sandstones (or quartzites) here named the Oquirrh formation. The name is assuredly appropriate—this formation is nearly twice as thick as all the previously discussed beds together and is the surface formation over far more than half of the range. It constitutes practically all of South Mountain and projects above the alluvium of Rush Valley in a number of knolls near Morgan Warm Spring.

Owing to the interbedding of limestones and sandstones, rapid erosion of the formation usually produces a ledge and slope topography, but quartzite and sandstone talus develops rather rapidly and soon masks the ruggedness of much of the terrane. The topography produced on the formation is illustrated in Plates 4 and 5.

Stratigraphy.—The Oquirrh formation,[4] to the lower part of which Spurr applied the descriptive name "Upper Intercalated series,"[5] is, as that name implies, a great series of interbedded limestones and coarse quartzites and sandstones, with very little dolomite and only subordinate amounts of shale. Quartzites, or silica-cemented sandstones, greatly predominate over lime-cemented sandstones throughout the formation, and there seems no systematic relation between the two varieties of cementing material. In this report the usage of the local mining men will be followed, and all the coarser clastic beds of the formation will be referred to as quartzites without implying that only silica-cemented clastic rocks are under discussion to the exclusion of the lime-cemented rocks. It will be clear from the context when the name is intended to imply the technical distinction.

The boundary drawn between the Oquirrh formation and the underlying Manning Canyon shale is an arbitrary one, as the two formations grade into each other. Where limestone becomes greatly preponderant over shale, the beds are assigned to the Oquirrh formation. There are few quartzite beds in the lower 1,000 feet of the Oquirrh formation, but they become thicker and more numerous higher in the section and constitute by far the greater part of the upper half of the unit.

The great mines of Bingham Canyon, just north of the Fairfield quadrangle, are in the higher beds of the Oquirrh formation. The rocks in this local area were long ago named the Bingham quartzite[6] and constitute the upper part of a conformable series of which Spurr's "Upper Intercalated series" is the lower part. The lithologic name quartzite, however, is hardly applicable to the entire series, for the lower part is chiefly limestone.

At least 8,000 feet and possibly 10,000 feet of this quartzite is exposed in the Bingham district.[7] About 8,000 feet of the formation is exposed below the lowest strata of the Bingham area between Butterfield Canyon, at the south edge of the Bingham district, and the Manning Canyon shale at the head of Iron Canyon. Thus the total thickness is probably 16,000 or 18,000 feet, depending on which of the Bingham measurements is accepted. The possibility of serious errors in measuring so great a thickness of strata which are nearly devoid of distinctive beds is very great, and the result may be in error by 20 per cent or perhaps more. But that the error involved is so great as to invalidate the order of magnitude of the thickness derived can be confidently denied, for a measurement of the section of the Oquirrh formation exposed between Selkirk Canyon and Iron Canyon (most of which is an evenly dipping monocline) gives a thickness of 17,000 feet. At South Mountain, where neither the top nor the bottom of the formation is seen, fully 11,000 feet of the formation is exposed with even westward dips on the southwest flank of the South Mountain anticline. In fact, it can be said with some confidence that the stratigraphically lowest rocks of South Mountain, those at the southeast end, are fully 3,000 feet and probably as much as 5,000 feet above the base of the Oquirrh formation, so that the section there indicates a total thickness of the formation in excess of 14,000 feet.

This tremendous thickness, which far exceeds that of the Pennsylvanian of any other locality in the entire Rocky Mountain province yet described, is so great that it appears almost inconceivable that the formation can not be subdivided—indeed, it seems at first glance that there must be some duplication of strata

[4] The name Oquirrh appears in a generalized section by C. R. Keyes (The grand staircase of Utah: Pan-Am. Geologist, vol. 41, p. 37, 1924) as a formation name within the "Weberian series," but as no description is given and the thickness as reported is wholly at variance with the field facts, it is thought that no confusion will be caused by the present usage of the term.

[5] Spurr, J. E., op. cit., p. 376.

[6] Boutwell, J. M., and others, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pp. 33–50, 1905.

[7] Idem, p. 35.

by overthrusting or step faulting which has led to such results of measurements. It can be said with great confidence, however, in view of the several sections measured and the simple folded structure of the beds, that the thickness is real and almost surely in excess of 15,000 feet.

Diligent search was made to locate distinctive beds that could be traced in order to effect correlations between the rocks of the Stockton and Bingham districts—one of the principal objectives of the survey. But detailed study has shown definitely that the quartzite beds that form so great a portion of the section are all lenticular and vary in thickness remarkably within very short distances along the strike. On tracing a bed whose thickness may be as great as 300 feet in a given locality it was observed to lens out to a knife-edge, perhaps within only half a mile. No single quartzite member of the 13 that were traced on the west slope of Lewiston Peak, where exposures are probably better than in any similar area of the quadrangles, could be followed for more than 4 miles; moreover, it was established that faulting has not occurred in this portion of the range. There is likewise evidence that some of the limestones also are lenticular, as has been stated by Keith and Boutwell with respect to the Bingham section. Their conclusions regarding the limestones have been questioned, however,[8] and no unequivocal evidence was discovered during this survey that would prove the lenticular nature of the limestones in the Stockton district. Nevertheless, several features suggesting such lensing were observed, and, in the opinion of the writer, it is probable that the lensing of the limestone is original and not merely due to strike faulting, though it is doubtless far less prevalent than that of the quartzites.

The three sections plotted in Figure 5 illustrate the rapid lateral variations in the formation. These sections are, in order from south to north, (1) on the west spur of Lewiston Peak, which rises above the saddle between the drainage basins of Mercur and Ophir Creeks; (2) on the spur forming the south wall of Hall Canyon; and (3) on the north spur of Hall Canyon. These sections, which were measured with tape and clinometer, are less than 2 miles apart, and in fact, Nos. 1 and 2 converge and are less than a quarter of a mile apart at their upper ends, yet it is evident on inspection that the striking lateral changes between them are so great as practically to preclude regional tracing of any particular member.

Despite these rapid variations, which prevent correlation of individual beds over any considerable distances, it is possible to map many subdivisions of the formation in certain areas. This has been done in great detail in the Bingham mining district by Keith

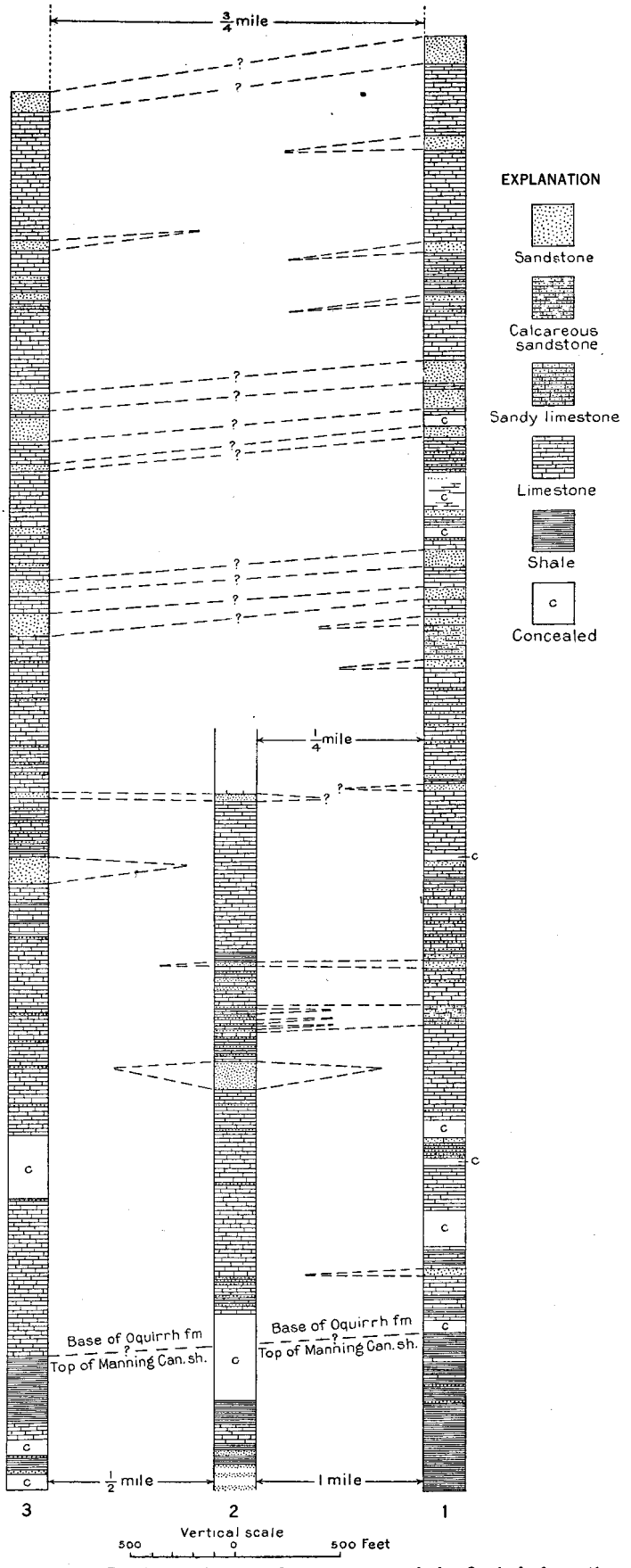


FIGURE 5.—Partial sections of the lower part of the Oquirrh formation measured on the west slope of Lewiston Peak, Fairfield quadrangle, showing lateral variations in beds. Correlations of some of the larger quartzite members are shown

[8] Walker, R. T. (geologist of the United States Smelting, Refining & Mining Co., Salt Lake City), oral communication.

and Boutwell,[9] and in still greater detail, as mining development has progressed, by the geologists of the mining companies. Similar work has been done in the Stockton district but has not been facilitated by large-scale maps and has not yet resulted in such detailed knowledge of the stratigraphy as has been obtained in Bingham Canyon. The local stratigraphy in the Stockton district will be discussed in the section treating of the economic geology of that area, as it is of purely local value.

Despite the failure to effect exact correlations between Bingham and Stockton, it can be stated that the highest productive bed at Stockton, that in the Ben Harrison mine, is roughly as far above the base of the formation as the Butterfield limestone of Butterfield Canyon (at about the base of the section of the Bingham district). Consequently, as nearly all the productive limestones of Bingham are over 1,000 feet higher than the Butterfield limestone and by far the greater part of the production at Stockton has been obtained from beds about 3,000 feet below those of the Ben Harrison mine, the local stratigraphy of one area can be of little or no assistance in the exploitation of the other unless entirely new ore-bearing beds are found.

The top of the formation does not occur in the Stockton and Fairfield quadrangles and may not be present anywhere in the range, although that can not be asserted in the absence of detailed study in the more northerly areas.

Age and correlation.—A number of collections of fossils were made from the lower and middle parts of the formation during this survey, in part by the writer and assistants but chiefly by Mr. Girty, who had previously collected extensively from the higher beds in the Bingham area.[10] All these collections are interpreted by Mr. Girty as indicating a Pennsylvanian age for the formation. His report is as follows:

> The Oquirrh formation, on the evidence of the faunas collected, appears to be of Pennsylvanian age throughout. As stated above, in the discussion of the fauna of the Manning Canyon shale, some of the lots of both the Manning Canyon shale and the Oquirrh formation appear to represent the Pottsville. The lots from the Oquirrh formation which have a Pottsville facies are 6266a, b, and c. Lots 6262 and 6271, on the other hand, should find place in the higher Pennsylvanian. Whether the group of beds represented by lots 6263, 6268, and 6269 are Pottsville or a little younger I would hesitate to say. Their faunas are in some respects anomalous. In the field I referred lot 6263 to the Pennsylvanian, and I might have referred lot 6268 to the Mississippian if Mr. Gilluly had not found that its stratigraphic position was above 6263. The fauna of these three lots does not occur in recognizable facies among our collections from the Gold Hill district, but it does occur without question in lot 2556b, collected many years ago in the Bingham district. In reporting upon the Bingham collections I felt satisfied that this lot was of Chester age because it contained spirals of the genus *Archimedes*, though I expressed that opinion in conservative language. Lot 6268, however, contains types that either were not found at all in lot 2556b or were not obtained in identifiable condition (such as *Marginifera splendens*). This fact, together with the stratigraphic relations of lots 6268 and 6263, removes any reasonable doubt that the geologic age of the former is not Pennsylvanian. Inasmuch as we have in these collections a type of fossil that has always been regarded as distinctively Pennsylvanian, *Chonetes mesolobus*, associated with *Archimedes*, which is all but confined to the Mississippian, the age of the fauna may fairly be held to be Pottsville. Indeed, *Chonetes mesolobus* occurs in abundance in the higher Pottsville of Ohio and also in beds that overlie the Morrow group, of upper Pottsville age, in Arkansas.
>
> The collections made from the Oquirrh formation in 1926 give little occasion for comment. Some of them may belong in the Pottsville zone. If so, they carry no recognizable evidence of this fact. For the most part they comprise species that are common in the post-Pottsville Carboniferous, though some of the species with scarcely recognizable variation occur in the Pottsville also. Specifically, I have in mind lots 6019, 6022, 6024, 6024a, and 6025. Of these lot 6019 possesses especial individuality and is especially distinct from the common run of Pennsylvanian faunas, but I can only point out its differences, not its affinities. The other lots in the list below are all referred to the Pennsylvanian, but more definite assignment is hardly warranted by our knowledge of the range of the species represented.
>
> 6019. From low mound near Morgan ranch, Rush Valley, Stockton quadrangle; collected by M. J. Buerger.
>
> | | |
> |---|---|
> | Cystelasma? sp. | Productus semireticulatus. |
> | Lioclema sp. | Productus semistriatus. |
> | Rhipidomella carbonaria. | Spirifer triplicatus var. |
> | Schizophoria texana. | Spiriferina kentuckyensis. |
>
> 6022. From about the same horizon as collection 6024a. West spur of Lewiston Peak at 9,950-foot contour, Oquirrh formation; collected by M. J. Buerger.
>
> | | |
> |---|---|
> | Syringopora multattenuata. | Marginifera splendens. |
> | Triplophyllum sp. | Spirifer triplicatus. |
> | Pinnatopora sp. | Spiriferina sp. |
> | Fenestella? sp. | Composita subtilita. |
> | Rhombopora lepidodendroides. | Cliothyridina orbicularis? |
> | Rhombopora sp. | |
>
> 6024. From limestone in Oquirrh formation just below pinnacle at 9,950-foot contour, west spur of Lewiston Peak, about 3,500 feet stratigraphically above the Manning Canyon shale; collected by M. J. Buerger:
>
> | | |
> |---|---|
> | Syringopora multattenuata. | Productus cora. |
> | Fenestella sp. | Productus pertenuis? |
> | Rhombopora lepidodendroides. | Marginifera splendens. |
> | Rhombopora sp. | Spirifer triplicatus. |
> | Streblotrypa prisca. | Squamularia perplexa? |
> | Derbya? sp. | Composita subtilita. |
> | Orthotetes aff. O. kaskaskiensis. | Hustedia mormoni. |
> | Dielasma sp. | Griffithides sp. |
>
> 6024a. From limestone about 100 feet below collection 6024, on west spur of Lewiston Peak; collected by M. J. Buerger:
>
> | | |
> |---|---|
> | Fenestella sp. | Derbya crassa. |
> | Polypora sp. | Chonetes sp. |

[9] Boutwell, J. M., and Keith, Arthur, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pl. 1, 1915.

[10] Girty, G. H., in Boutwell, J. M., and others, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pp. 387–393, 1925.

Productus cora.
Productus cora var.
Pustula nebraskensis?
Spirifer triplicatus.
Spirifer opimus.
Composita subtilita.
Aviculipecten sp.
Ostracoda indet.

6025. From limestone at 8,900-foot contour on west spur of Lewiston Peak, about 1,500 feet above base of Oquirrh formation; collected by M. J. Buerger:

Stenopora carbonaria.
Orthotetes aff. O. kaskaskiensis.
Productus cora.
Spirifer opimus var. occidentalis.

6261. From limestone on north side of Soldier Creek about half a mile west of the canyon mouth, west of the Soldier Canyon fault; collected by G. H. Girty and James Gilluly:

Syringopora sp.
Fenestella sp.
Pinnatopora sp.
Rhombopora lepidodendroides.
Streblotrypa prisca?
Cystodictya sp.
Orthotetes aff. O. kaskaskiensis.
Productus semireticulatus.
Squamularia perplexa.
Sphaerodoma? sp.
Griffithides sp.

6262. West end of South Mountain, Stockton quadrangle, upper part of Oquirrh formation (Pennsylvania); collected by G. H. Girty and James Gilluly:

Fusulina secalica.
Fistulipora sp.
Stenopora aff. S. carbonaria.
Rhombopora lepidodendroides.
Orbiculoidea sp.
Schizophoria sp.
Orthotetes aff. O. kaskaskiensis.
Chonetes aff. C. verneuilianus.
Productus semireticulatus.
Squamularia perplexa.
Spiriferina spinosa.
Hustedia mormoni.
Pteria? sp.
Acanthopecten carboniferus?
Bellerophon? sp.
Euconospira sp.

6263. East tip of South Mountain, Stockton quadrangle, north side of Rush Lake, lower part of Oquirrh formation (Pennsylvania); collected by G. H. Girty and James Gilluly:

Fenestella several sp.
Archimedes aff. A. laxus.
Pinnatopora aff. P. pyriformipora.
Polypora several sp.
Acanthocladia n. sp.
Drymotrypa? n. sp.
Rhombopora lepidodendroides.
Streblotrypa prisca.
Cystodictya sp.
Prismopora triangulata?
Chonetes mesolobus var. decipiens.
Chonetes granulifer.
Productus semireticulatus.
Productus ovatus var. minor.
Squamularia perplexa?
Hustedia mormoni.
Aviculipecten sp.
Platyceras n. sp.
Griffithides sp.

6266a. From the first 200 feet above Manning Canyon shale, north side of Soldier Canyon, about half a mile above canyon mouth; collected by G. H. Girty and James Gilluly:

Hydreionocrinus aff. H. acanthophorus.
Fistulipora sp.
Rhombopora lepidodendroides.
Cystodictya aff. C. divisa.
Productus cora.
Productus semireticulatus var.
Avonia aff. A. arkansana var. multilirata.
Pustula aff. P. semipunctata.
Spirifer opimus var. occidentalis.
Spirifer aff. S. wellsianus.
Spiriferina spinosa var.
Composita subtilita.
Cliothyridina orbicularis?
Aviculipecten aff. A. pellucidus.

6266b. Scattered up to lowest quartzite of the Oquirrh formation, above collection 6266 and at same locality; collected through a stratigraphic interval of about 1,000 feet by G. H. Girty and James Gilluly:

Echinocrinus sp.
Fistulipora sp.
Fenestella sp.
Rhombopora lepidodendroides.
Schizophoria sp.
Orthotetes aff. O. kaskaskiensis.
Chonetes sp.
Productus cora.
Productus semireticulatus var.
Avonia arkansana?
Pugnoides sp.
Spirifer opimus var. occidentalis.
Spiriferina sp.
Composita subtilita.
Aviculipecten aff. A. pellucidus.
Myalina sp.
Ostracoda indet.

6266c. Above lowest quartzite of Oquirrh formation, same spur as collections 6265a, 6266, 6266a, and 6266b; includes fossils from over 2,000 feet of beds extending to the top of the 7,525-foot hill; collected by G. H. Girty and James Gilluly:

Chaetetes milleporaceus?
Productus cora.
Composita subtilita.

6268. From 200 to 300 feet stratigraphically above lot 6263, on southeast corner of South Mountain, on next spur south of lot 6263; contains *Archimedes* but is stratigraphically above *Chonetes mesolobus;* collected by G. H. Girty:

Sponge spicules.
Triplophyllum? sp.
Fistulipora sp.
Batostomella sp.
Leioclema sp.
Fenestella several sp.
Polypora several sp.
Pinnatopora aff. P. pyriformipora.
Pinnatopora sp.
Archimedes aff. A. laxus.
Septopora sp.
Rhombopora sp.
Orbiculoidea sp.
Orthotetes aff. O. kaskaskiensis.
Chonetes granulifer.
Productus cora.
Marginifera splendens.
Marginifera splendens var.
Pustula nebraskensis?
Pustula aff. P. symmetrica.
Spirifer cameratus var.
Spirifer opimus var. occidentalis.
Spirifer sp.
Squamularia perplexa?
Composita subtilita.
Acanthopecten carboniferus var.
Aviculipecten aff. A. pellucidus.
Phillipsia major?

6268a. Essentially the same locality as 6268, 6269, and 6263, but about 1,000 feet stratigraphically above 6268; collected by James Gilluly:

Fusulina secalica

6269. Above collection 6263, on same spur, probably overlying horizon of lot 6268, Oquirrh formation; collected by G. H. Girty and James Gilluly:

Stenopora.
Fenestella several sp.
Archimedes aff. A. laxus.
Chonetes granulifer.
Pustula nebraskensis.
Marginifera splendens.
Marginifera splendens var.
Spirifer opimus var. occidentalis.
Spirifer cameratus.
Composita subtilita.
Griffithides sp.

6271. From quartzite at northeast end of Traverse Mountains, in sec. 13, T. 2 S., R. 4 W., Fairfield quadrangle, upper part of Oquirrh formation; collected by James Gilluly:

Fusulina cylindrica

The Oquirrh formation of the Gold Hill quadrangle [11] consists of roughly 5,000 feet of limestone, sandstone, chert, conglomerate, and shale of Pennsylvanian age and is considered to be a correlative of the typical Oquirrh formation. It is highly probable that the Weber quartzite of the Wasatch Range is equivalent to some part of the Oquirrh formation, but the Weber is only 2,000 feet thick in the Park City

[11] Nolan, T. B., op. cit.

district and 1,350 feet in Big Cottonwood Canyon,[12] thicknesses which are minor fractions of that of the great Oquirrh formation. Farther north, in the Randolph quadrangle, according to Richardson,[13] the Wells formation, the only representative of the Pennsylvanian in that region, ranges from 300 to 600 feet in thickness and rests unconformably upon the Brazer limestone. Still farther north, in southeastern Idaho, Mansfield[14] found the Wells formation to be about 2,400 feet thick and to be unconformable on the Brazer as well as limited at the top by an unconformity. To the south, in the San Francisco district,[15] about 1,400 feet of quartzite and limestone assigned to the Talisman quartzite and Elephant limestone are referred to the Pennsylvanian. Probably all these Pennsylvanian rocks are partial equivalents of the Oquirrh formation, but exact correlations between these areas are at present impossible.

Conditions of deposition.—The remarks on pages 28–29, with reference to the conditions of sedimentation prevailing during the deposition of the Humbug formation apply with equal force to the deposition of the Oquirrh formation. The area must have been subjected to widely fluctuating currents, with tremendous amounts of detritus, almost wholly of sand, supplied by the strong currents and with great quantities of lime available for deposition during more quiet times. The numerous fossils of the limestone layers and the grain and bedding of the sandstones show that at no time were the waters very deep, yet no continental deposits have been recognized in the formation, and it seems likely that the rate of deposition never exceeded that of depression in the district. This means that the sea floor on the site of the Oquirrh Mountains sank for at least 3 miles during the deposition of the Oquirrh formation and over 4 miles during the whole Carboniferous period, although that site had been a stable or even a dominantly positive area probably from Upper Cambrian time.

REGIONAL CORRELATION OF THE CARBONIFEROUS OF WESTERN UTAH

The sections of Carboniferous rocks of western Utah that have been studied in detail are shown diagrammatically in Plate 7. It is evident from these diagrams that there is no such uniform trend toward westward thickening of these formations as characterizes the Cambrian formations, nor is there uniformity along a northeasterly line similar to that of the Cambrian rocks.

More specifically, the Madison rocks show a slight thinning along an east-west line and finally are overlapped by limestones of Brazer age in the southern part of the Gold Hill quadrangle. A general tendency of these rocks to thin southward also appears.

With the upper Mississippian an era of very active sedimentation began in the Oquirrh Mountains. The eastern edge of the area of greatest sedimentation must have been between the Oquirrh Mountains and the middle of the Wasatch Range; toward the west the section, according to the meager available evidence, thins much less rapidly. That the depressed trough which received these sediments on the present site of the Oquirrh Mountains was not very greatly elongated parallel to the present structural trend appears likely from the sections of Plate 7, B. This figure shows that rocks of this age are less than 2,000 feet thick both in the San Francisco district and in the Randolph quadrangle. The Humbug is the highest Paleozoic formation exposed at Tintic, so it can not be told from the evidence at hand whether or not the area of great depression of Brazer time included this district also.

The east-west sections shown in Plate 7, A, show that conditions during Pennsylvanian time were similar to those of the upper Mississippian. On the site of the Oquirrh Mountains one of the thickest sections of the Pennsylvanian yet described in the world was laid down. The area subject to this great sedimentation was probably rather small, as none of the other districts that have been studied in the region have shown thicknesses even remotely approaching this.

Figure 6 brings together in generalized form most of the data available on the thickness of the Paleozoic rocks of this portion of the Great Basin.

These sections indicate that the Oquirrh and middle Wasatch areas, which were near the border of the Middle Cambrian geosyncline, were subjected to deeper erosion in pre-Devonian and pre-Mississippian time, or else that they were consistently seats of less active sedimentation during the early and middle Paleozoic than the other areas represented; because, whereas in the other districts a considerable thickness of Ordovician rocks rests on the Upper Cambrian, in the Oquirrh Mountains the Devonian, and in the southern Wasatch the Mississippian, are the lowest post-Cambrian rocks present. Whichever interpretation is placed on these stratigraphic relations, they indicate that the Oquirrh and southern Wasatch area, compared to the other districts of which detailed sections are available, was one of more positive tendency in pre-Mississippian time. This tendency was reversed in a most striking manner during Carboniferous time, as is seen from the great thickness of the Carboniferous of the Oquirrh Mountains—over 20,000 feet. This thickness is much greater than that of any other Carboniferous section so far found in the entire Rocky Mountain region of the United States. From a dominantly positive area in pre-Carboniferous time

[12] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 46, 1912.
[13] Richardson, G. B., op. cit., p. 415.
[14] Mansfield, G. R., op. cit., pp. 71–73.
[15] Butler, B. S., op. cit. (Prof. Paper 80), pp. 36–37.

the area became, during the Carboniferous, one of the most strikingly negative areas yet known.

TERTIARY SYSTEM

CONGLOMERATE

Distribution and topographic expression.—Conglomerates and coarse sandstones considered to be of Tertiary age occur in two small areas in secs. 23 and 26, T. 4 S., R. 2 W., near the northeast corner of the Fairfield quadrangle. The larger body forms the crest and upper and western slopes of the prominent 6,355-foot hill; the smaller outcrop is across the gulch to the southeast. The rock in places is poorly cemented and weathers into slopes but for the most part is well cemented and forms prominent ledges, especially on the west slope of the hill.

Stratigraphy.—The conglomerate rests with marked angular unconformity upon a surface of very strong relief. For the most part the beds of the Oquirrh formation dip very steeply, and rather high dips occur also in the conglomerate. The attitude of the conglomerate may be fairly said to be nearly normal to that of the Oquirrh formation.

The contact between the conglomerate and the Tertiary eruptive rocks is poorly exposed, but inasmuch as the conglomerate is composed almost wholly of volcanic detritus there can be no question of its younger age. There is also a very probable overlap of the conglomerate upon the volcanic rocks. Near the contact there appears to be some discordance in dip between them, but this is not quite certain.

The conglomerate is in thick beds, rather blocky and massive. The beds are made up of fine gravel, chiefly of various volcanic rocks, crystals, and glass. The fragments are subrounded to subangular, and the largest are about 5 centimeters in diameter, though most are nearer 2 or 3 millimeters. They are cemented by silica. The greatest thickness of the conglomerate exposed is on the west flank of the 6,355-foot hill. Here the rocks dip about 32° N., and about 200 feet of beds were estimated to be present.

Age and correlation.—As no fossils were found in the conglomerate, positive evidence of its age is lacking, and its geologic relations furnish the sole clue. Inasmuch as the conglomerate is composed of volcanic débris of evident local origin, it is younger than the volcanic rocks. The lavas (see p. 65) are almost surely late Eocene, and this suggests that the age of the conglomerate is later than Eocene. The fact that

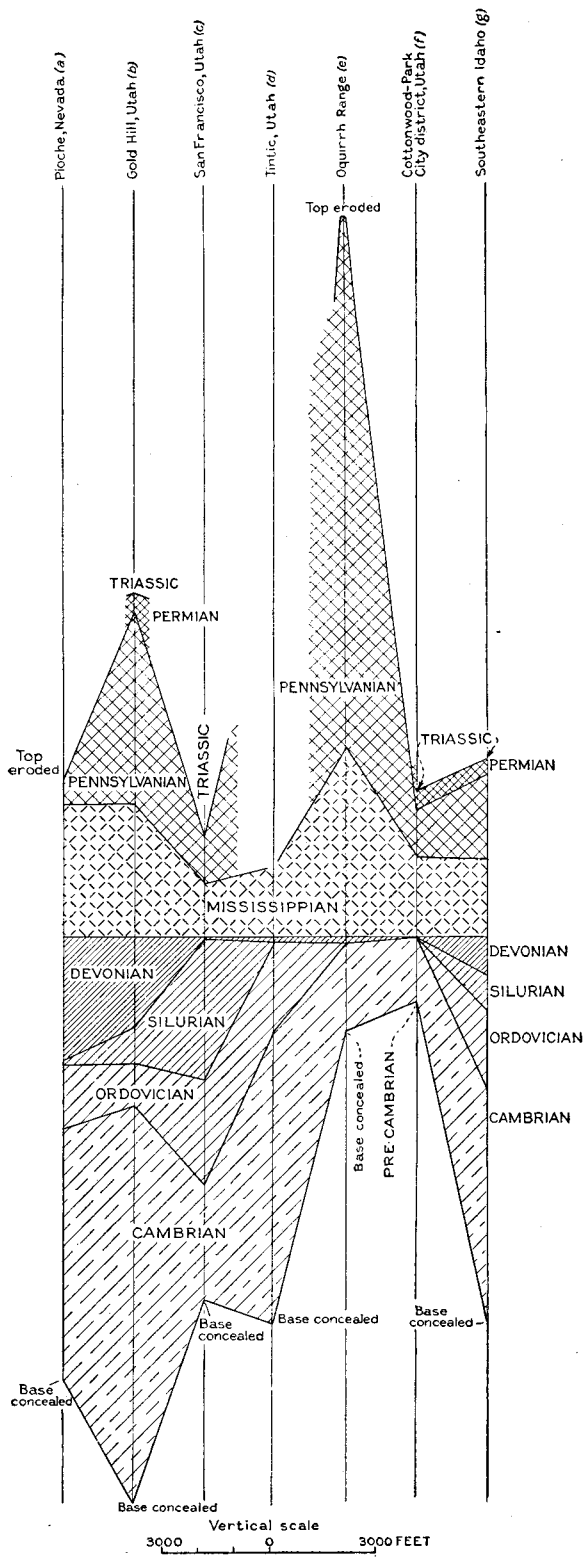


FIGURE 6.—Eastward shift in site of thick sedimentation between pre-Carboniferous and Carboniferous time in western Utah, southeastern Idaho, and eastern Nevada, as shown by stratigraphic sections. (*a*) Westgate, L. G., and Knopf, Adolph, Geology of Pioche, Nev., and vicinity: Am. Inst. Min. and Met. Eng. Trans., [preprint] 1647, 1927. (*b*) Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation). (*c*) Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 29, 1913. (*d*) Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah; U. S. Geol. Survey Prof. Paper 107, p. 22, 1919. (*e*) This report. (*f*) Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 235, 239, 295, 1920. (*g*) Mansfield, G. R., Geography, geology, and mineral resources of a part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 50–52, 1927.

the conglomerate has been strongly folded, with present dips as high as 32° (diverging in a manner which precludes the possibility that these dips may be original), together with the dissection which has occurred since the gravel was deposited, leads to the impression that it is probably pre-Pliocene, and it is here tentatively classified as Oligocene or Miocene.

The facts just mentioned show at any rate that the conglomerate long antedates the Lake Bonneville epoch of the Pleistocene, for no folding or erosion comparable to that which has affected these rocks is known anywhere in the Pleistocene of the Bonneville Basin. Furthermore, the altitude at which the beds occur is such that a very long period of erosion must be invoked to account for the removal of the portions of the conglomerate together with considerable subjacent rock which must once have surrounded the present residual bodies.

QUATERNARY SYSTEM

Surficial deposits of Quaternary age occupy a very large part of the Stockton and Fairfield quadrangles. These deposits are of four principal varieties—alluvium, including fanglomerate; Lake Bonneville sediments; talus deposits; and glacial moraines. All these varieties are grouped together on Plate 12.

ALLUVIUM AND FANGLOMERATE

Rush, Tooele, and Cedar Valleys are very largely floored with deposits laid down by the streams rising in the mountains. These deposits form huge fans with apexes at the mouths of the mountain canyons and with gradients flattening to lower and lower angles as the lowlands are approached. In the lower parts of the valleys they coalesce with and are partly covered by the lacustrine deposits of Lake Bonneville and its relics, such as Rush Lake.

The material making up these fans is coarsely stratified, of characteristically poor sorting and with little cementing material, composed of boulders of all sizes, the largest several feet in diameter, cobbles, sand, and silt in heterogeneous arrangement. There is little or no sorting of the finer material from the coarser, and the included rocks depend in composition solely upon the source material. To this material, which is the characteristic alluvium of the Basin and Range province, the name "fanglomerate" has been appropriately given.[16]

The thickness of these fanglomerate deposits is of course variable, depending not only upon the nearness to the source of material but also on the topography of the bedrock basement. Several shafts west of Mercur Canyon are at least 300 feet deep and show only fanglomerate material on their dumps, and a well at Clover penetrated only unconsolidated sediments to a depth of more than 1,000 feet.[17]

Locally, at least, and presumably in areas favorably situated with respect to the more permeable portions of the deposits, the fanglomerate is cemented by lime to form caliche. Even the caliche is usually rather poorly cemented, however. It is evidently formed at a temporary perched water table a short distance below the surface, for it is rarely exposed except in the walls of the very young gullies that locally strip the fans.

In addition to the fanglomerate normal stream sediments occur in the lower parts of the mountain canyons. These deposits are all small and nowhere more than a few feet deep.

LAKE BONNEVILLE BEDS

The deposits of Lake Bonneville floor the lowest parts of Rush, Tooele, and Cedar Valleys. These deposits include well-bedded lake silt in the lowest depressions and the coarse gravel and sand spits and bars which are the direct product of shore processes. Among these shore features the most striking are the great bar and spit at Stockton, which have been exhaustively discussed by Gilbert.[18]

The lacustrine deposits form a veneer over the lower parts of the alluvial slopes. Within the area of this survey this veneer is probably nowhere more than a few feet thick. The smooth concavity of the basins is due much more probably to reworking of unconsolidated materials by the shore processes of the lake during rising and falling stages than to the deposition of sufficient silt to mask the alluvial topography.

TALUS DEPOSITS

The talus deposits of the area are generally small. The largest occur below the cliffs that were oversteepened by glaciation, such as those at the head of Settlement Canyon (pl. 3, *C*, *B*), Mill Canyon, and The Jumpoff. Where the Humbug and Oquirrh formations appear at the surface, talus is generally present, owing to the angular character of the quartzite débris from these formations.

GLACIAL MORAINES

Evidence that very small glaciers, perhaps merely névé fields, occupied the highest northward-facing valleys of the Oquirrh Mountains, presumably during Wisconsin time, is afforded by small cirque lakes, such as those at the head of the first canyon north of Hall Canyon and below The Jumpoff; by roches mouton-

[16] Lawson, A. C., The petrographic designation of alluvial-fan formations: California Univ. Dept. Geology Bull., vol. 7, pp. 325–334, 1913.

[17] Carpenter, Everett, Ground water in Boxelder and Tooele Counties, Utah: U. S. Geol. Survey Water-Supply Paper 333, p. 77, 1913.

[18] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 137, 149–151, pls. 9, 20, 1890.

nées, seen in these two localities and in Mill Canyon and Jackson Hollow; by moraine topography in all the above-named localities; and by "steps" in the profile of these several valleys. The glaciers were all above 8,000 feet and most of them above 8,500 feet in altitude. The largest was less than a mile long, and the moraines they left were also correspondingly small, the largest one, below The Jumpoff, being only a few hundred feet long.

IGNEOUS ROCKS

GENERAL FEATURES

Both intrusive and extrusive igneous rocks occur in the Stockton and Fairfield quadrangles. The extrusive rocks cover by far the larger area, but except for a small outcrop near the northeast foot of South Mountain, in the Stockton quadrangle, they are limited to the northeast corner of the Fairfield quadrangle. They are chiefly latite and quartz latite, with some minor flows of basalt, rhyolite obsidian, and nephelite basalt. Among the extrusive rocks, flows, although numerous, are quantitatively subordinate to breccias. The intrusive rocks include numerous small stocks, dikes, volcanic plugs, and sills, distributed at intervals from Butterfield Canyon in a belt toward Stockton and thence down the west front of the range to the Mercur district. No large bodies of intrusive rock are included in the area, but just north of the Butterfield Canyon localities is the considerable stock of the Bingham mining district. The intrusive rocks are chiefly of monzonitic and rhyolitic composition but include also andesite (or latite), lamprophyre, and nephelite basalt.

The order of eruption is uncertain, as but few contacts between the igneous rocks occur. However, there is indisputable evidence that at least one of the monzonitic bodies intrudes members of the extrusive series and is therefore younger.

A striking unconformity between the extrusive rocks and the underlying sedimentary rocks is conclusive proof that the volcanism was much later than the orogenic folding of the Oquirrh Mountains.

EXTRUSIVE ROCKS

SUBDIVISIONS

Volcanic rocks occur in two distinct areas in the Stockton and Fairfield quadrangles, although there is considerable probability that the areas were formerly continuous and have been separated by later faulting and erosion. The smaller area lies at the northeast foot of South Mountain, in the Stockton quadrangle, where a body of hypersthene latite or andesite tuff and breccia is exposed in a belt a few hundred feet wide and about 2 miles long. The other area is about 12 miles to the east, on the eastern flanks of the Oquirrh Mountains, covering most of the northeastern part of the Fairfield quadrangle. This volcanic field continues still farther east and covers much of the Traverse Mountains, including the spur at the Point of the Mountains, east of Jordan Valley.[19] It also extends north of the Fairfield quadrangle along the base of the Oquirrh Mountains east of Bingham.[20] The volcanic rocks of this field include augite andesitic latite,[21] hypersthene latite, quartz latite, nephelite basalt, olivine basalt, rhyolitic obsidian, and trachyte.[22]

SOUTH MOUNTAIN, STOCKTON QUADRANGLE

HORNBLENDE-HYPERSTHENE ANDESITE OR LATITE BRECCIA

Field relations.—The volcanic rocks of the northeast foot of South Mountain, in the Stockton quadrangle, include breccias, water-laid tuffs, and flows. The breccias are the most abundant, though flows are numerous in the southern part of the area. The interbedded water-laid tuffs give opportunity to ascertain the attitude of the rocks. They strike about N. 55° W. and dip about 18° NE., so that the flows appear to underlie the breccias and tuffs. The outcrop of the volcanic rocks is completely surrounded by alluvium and lake deposits, which are without question much younger than the volcanic rocks.

Lithology.—The breccias consist of angular to subrounded fragments, the largest 6 feet or more in length, set in a matrix of smaller fragments. Bedding is obscure or entirely absent where the coarser fragments are most numerous but can be determined in many finer layers. (See pl. 8, *A*, *B*.)

A representative collection of specimens from the larger breccia fragments includes few varieties. The dominant rock of the breccia is medium to dark gray, dense, and somewhat vesicular, with recognizable hornblende and plagioclase phenocrysts somewhat less than 1 millimeter long in an aphanitic groundmass. Subordinate varieties carry larger phenocrysts, as much as 3 millimeters long. Weathering produces various hues of purplish gray, red, and red-brown.

Under the microscope the rock is seen to be microporphyritic, with microphenocrysts of plagioclase, hypersthene, augite, basaltic hornblende, and biotite set in a groundmass of plagioclase laths, some glass, and zeolites. The texture of the groundmass is felted, with a rough tendency toward a linear arrangement of the

[19] Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 440–441, 1877.

[20] Boutwell, J. M., and others, The geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pp. 55–56, 1905.

[21] Emmons, S. F., op. cit., p. 440.

[22] Zirkel, Ferdinand, Microscopical petrography: U. S. Geol. Expl. 40th Par. Rept., vol. 6, pp. 132, 156, 1876. The "trachyte" from the Traverse Mountains described by Zirkel would probably be now classed as a latite. It probably differs but little from rocks described in the present report as latite. Although true trachyte has been found in the area, it was determined only from a few fragments in an andesitic breccia and can hardly be an important rock in the district.

crystals (pilotaxitic texture). The plagioclase phenocrysts reach 1 millimeter in greatest length. They are strongly zoned, with a composition ranging from about $Ab_{40}An_{60}$ in the cores to about $Ab_{60}An_{40}$ in the border zones. Carlsbad, albite, and pericline twinning occurs. In most specimens hypersthene is the dominant mafic mineral, although in some it is subordinate to hornblende. The hypersthene occurs in fairly well formed crystals as much as 1 millimeter long. Most of it is strongly pleochroic (X=Y reddish, Z pale green), but this feature is variable, and in some specimens the pleochroism is barely discernible, although the mineral is readily determined by its parallel extinction, low birefringence, and negative character. Basaltic hornblende is commonly the next most abundant mafic mineral and in a few slides exceeds the hypersthene quantitatively. It is strongly pleochroic (X yellowish brown, Z=Y dark reddish brown). The extinction angle is small, ranging from 12° in some specimens to practically zero. Commonly the hornblende is surrounded by a reaction rim of magnetite and pyroxene. Augite is a subordinate mafic mineral, not exceeding 3 per cent of the rock. One or two slides show a little biotite, but it is rare. Apatite and magnetite are accessory primary minerals, and calcite is present as an alteration product in some slides.

Over 60 per cent of the rock is composed of the groundmass, which consists of minute plagioclase laths set in a cryptocrystalline to glassy base. These plagioclase laths can hardly be more calcic than $Ab_{60}An_{40}$ and may be as sodic as $Ab_{70}An_{30}$. Some undoubted glass is interstitial, but there is probably some alkalic feldspar in the base as well. A little analcite replaces plagioclase phenocrysts along cracks, and some opal lines minute cavities. Very minute radiating crystals of low birefringence, negative elongation, and low refraction occur in some vesicles and may be tridymite, but their identity could not be established. The tuffs were not examined microscopically, but there is no reason to doubt their close relationship with the breccias.

The specimens examined vary so slightly in composition that all may be fairly characterized from their microscopic features as hornblende-hypersthene andesite. However, the rocks closely resemble the breccias of the east flank of the range, which would also be classed, from their recognizable minerals, as andesites; but the glassy or cryptocrystalline groundmass contains so much potash that the entire rock proves on chemical analysis to be higher in potassa than in soda and falls into the group of latites. It seems probable that the "andesites" just described would also, on chemical analysis, prove to be latitic. This suggestion is based not alone on the resemblance of these rocks to the latites of the Fairfield quadrangle, but also upon the fact that by far the greater part of the rocks in western Utah that have been called andesite from their mineralogy have proved to be latitic when subjected to chemical analysis. Such rocks have now been described from Park City,[23] Tintic,[24] San Francisco,[25] Iron Springs,[26] and Gold Hill,[27] as well as this area.

TRAVERSE MOUNTAINS

GENERAL FIELD RELATIONS

The volcanic rocks of the Traverse Mountains and the eastern slopes of the Oquirrh Mountains were poured out over a surface very similar in degree of dissection though not in geographic relations to that of the present time. The prevolcanic surface was one of considerable relief, some of the valleys being not less than 1,000 feet lower than heights less than a mile distant. In consequence of this and doubtless in part because of unequal distribution of the erupted materials and of variations in erosion between successive eruptions, the volcanic series presents different facies at its base in different parts of the area. Thus the only volcanic rock in place on the south side of West Canyon is a small body of olivine basalt just below the mouth of Iron Canyon. In sec. 2, T. 5 S., R. 2 W., in Tickville Gulch, the rock at the base of the volcanic series is locally a light-green rhyolitic obsidian, but not far away it is a latite breccia. In the west fork of Tickville Gulch it is quartz latite, but in the northern part of secs. 3 and 4, T. 5 S., R. 2 W., the lowest member of the volcanic series is a latite. By far the dominant materials toward the base of the volcanic series, however, are latitic pyroclastic rocks, and there can be little doubt that these rocks represent the principal product of the earliest volcanism of the region. Flows become increasingly more abundant toward the top of the preserved portion of the volcanic section, and east of a line from Oak Spring Canyon to Step Mountain they form much the greater part of the series.

It is quite impossible to determine accurately from surface observations the thickness of the volcanic rocks exposed in this area. West of Rose Canyon, in the angle between this canyon and Water Fork, however, there is not less than 1,900 feet of latitic breccia with subordinate lavas. These rocks are overlain east of Rose Canyon by not less than 1,000 feet of lava and subordinate breccias. Inasmuch as both these esti-

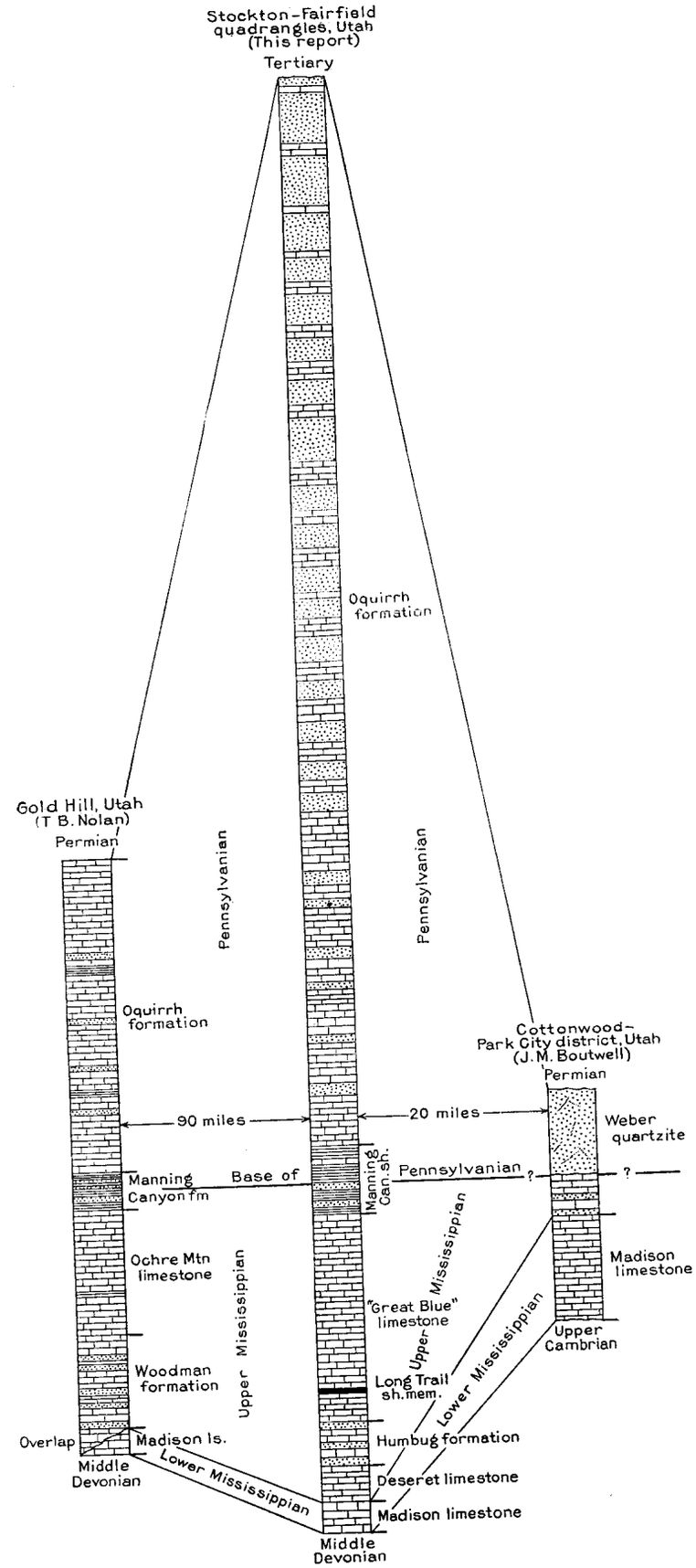
[23] Boutwell, J. M., and Woolsey, L. H., Geology and ore deposits of the Park City mining district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 74, 1912.

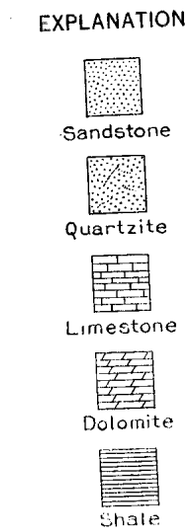
[24] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 55, 63, 67, 1919.

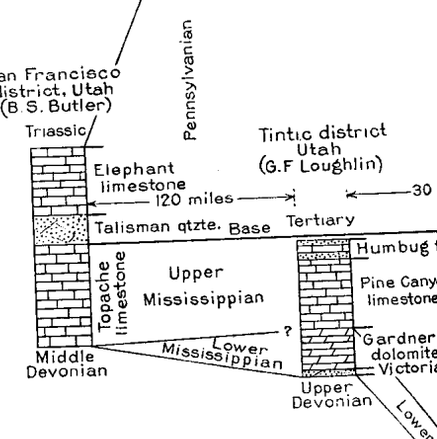
[25] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 49, 1913.

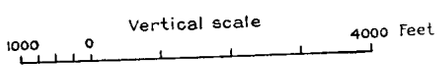
[26] Leith, C. K., and Harder, E. C., Iron ores of the Iron Springs district, Utah: U. S. Geol. Survey Bull. 338, p. 58, 1908.

[27] Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation).

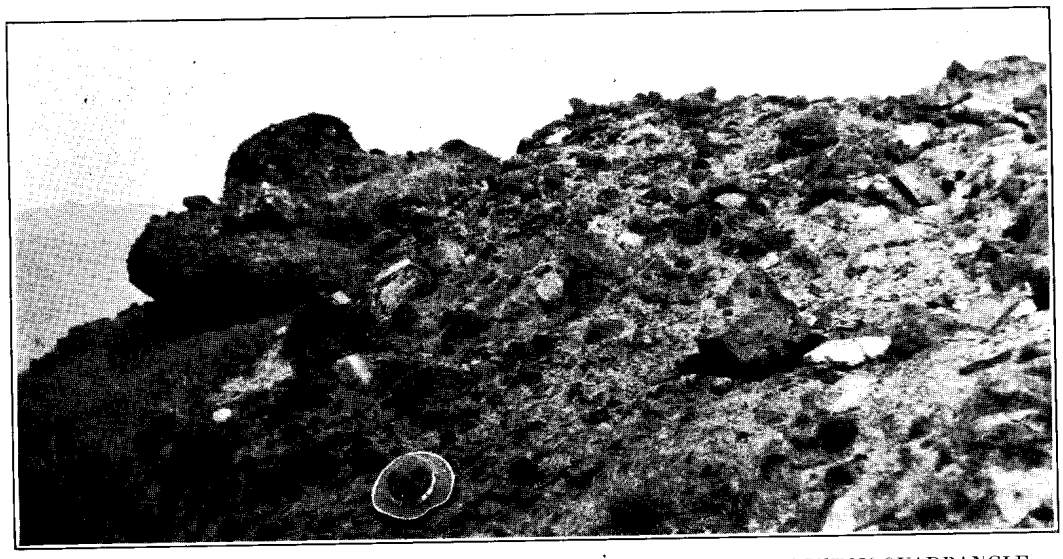








CORRELATION AND VARIATIONS OF MISSISSIPPIAN AND PENNSYLVANIAN FORMATIONS



A. ANDESITE BRECCIA AT NORTHEAST FOOT OF SOUTH MOUNTAIN, STOCKTON QUADRANGLE

B. VOLCANIC TUFF, OVERLAIN BY ANDESITE BRECCIA, ON DIVIDE BETWEEN STOCKINGS FORK AND CITY CANYON, FAIRFIELD QUADRANGLE

C. WATER-LAID TUFF ON DIVIDE BETWEEN CITY CANYON AND WATER FORK, FAIRFIELD QUADRANGLE

mates are conservative and there has been very considerable erosion, it is quite certain that locally the original thickness of the volcanic series exceeded 3,000 feet, and it may have been much greater.

The volcanic series of the Traverse and eastern Oquirrh Mountains has been somewhat deformed since its extrusion. Eastward dips of 10° to 15° characterize most of the series west of a line between Rose Canyon and Oak Spring Canyon; east of this line the rocks lie either nearly horizontal or with dips rarely exceeding 4° and having no apparent system. Many of the water-laid tuff members that are interbedded with the breccias are composed of such fine materials that it is highly probable that they could not have had original dips of more than 1° or 2°. Accordingly the dips of 10° and more are probably due to postvolcanic deformation. This deformation was doubtless in part a result of the eastward tilting of the Oquirrh Mountains as a whole, for which independent evidence is advanced in the section of this report on structural geology (pp. 81–88). The minor and apparently unsystematic folding in the Traverse Mountains may readily have been due to differential vertical movements in the crust above a magma reservoir during and after its volcanic activity. Similar irregularities that may have existed west of Rose Canyon could be detected with difficulty if masked by the dominant eastward tilt of the rocks in that area.

GENERAL PETROLOGIC FEATURES

A considerable diversity of types occurs among the volcanic rocks of the Traverse Mountains. Breccias and tuffs predominate, but flows are very numerous and of considerable thickness. With two exceptions, however, despite the variety of structural and textural characters, all the rocks studied are of latitic to quartz latitic composition. Microscopic study alone would classify the rocks almost wholly as andesites or dacites, but chemical analyses demonstrate that nearly all the flows carry notable quantities of potassa and should be classed as latites or quartz latites. However, potash feldspar occurs as phenocrysts only in one rock collected—a fragment of trachyte from a dominantly latitic breccia. Owing to the relatively poor exposures of the volcanic series, the considerable relief of its under surface, the lenticular character of its individual members, and the general lithologic similarity of the breccia fragments and flow rocks, no attempt was made to map the different members of the series. Two varieties whose composition differs notably from that of the main mass of the volcanic rocks were distinguished in the field. One of these is the body of olivine basalt exposed on the south side of West Canyon just below the mouth of Iron Canyon. The other is a small flow of nephelite basalt which caps a small hill in the NE. ¼ sec. 31, T. 4 S., R. 2 W., just east of Sheep Ridge.

LATITIC BRECCIAS

Field relations.—Although locally underlain by flows, as mentioned above, latitic breccias are usually found at the base and predominate throughout the lower half of the volcanic series.

Bedding is almost lacking in many breccia members, but most outcrops show a faint stratification or contain enough interbedded tuff layers to furnish information as to the attitude of the rocks. (See pl. 9, *A*.) The rock fragments composing the breccia range widely in size, from dust-like particles to huge masses 6 or 8 feet long or even larger. No statistical study was attempted, but the impression was received that the bulk of the breccia is composed of fragments ranging from 3 inches to a foot in diameter. No systematic variations in size of the fragments that might serve as a clue to the source of the material were discovered.

The principal bodies of latitic breccia lie west of a line between Rose Canyon and Oak Spring Canyon, although there are considerable bodies east of this line. The former extent must have been very much greater, for fragments of breccia were found on Long Ridge at the 6,300-foot contour, a few hundred feet east of bench mark 6604, and other fragments of unmistakably similar rock were seen at an altitude of 7,700 feet on the spur west of the head of Iron Canyon.

Lithology.—The varieties of rock found as fragments in the breccia comprised biotite-hornblende latite or andesite, biotite-augite latite or andesite, olivine basalt (very little), and biotite-augite trachyte (only one fragment seen).

The biotite-hornblende latite or andesite, which is by far the most abundant of the breccia fragments, is a medium-gray to purplish-gray porphyritic rock that weathers to various shades of reddish brown and purple. Biotite, plagioclase, and hornblende are recognizable as phenocrysts, set in a dense groundmass. A few of the mafic phenocrysts reach 1 centimeter in length, but the feldspar crystals only exceptionally exceed 1 millimeter. The microscope shows that the feldspar phenocrysts are zoned, with a composition showing the very considerable range from about $Ab_{30}An_{70}$ to about $Ab_{65}An_{35}$. The zoning is normal—that is, the external zones are more sodic than the core, with only a few alternations. Albite and carlsbad twins are characteristic. The hornblende is of the basaltic variety, with X light greenish brown, Y dark brown, and Z very dark brown. The extinction angle is 7°. Alteration to magnetite has been intense along the borders. Biotite, of quite normal pleochroism and with sagenite crystals well developed, occurs in

euhedral plates. Magnetite and apatite are accessories. The groundmass is felted, with minute plagioclase laths of composition about $Ab_{65}An_{35}$ set in a glassy base of greater or less abundance (hyalopilitic ranging to pilotaxitic). A little analcite occurs as an alteration product of the plagioclase. The texture and mineral composition of this rock are like those of biotite-hornblende andesite. The chemical analyses of similar rocks of the area, however, suggest that this too is really a latite. Some specimens carry augite in addition to the biotite and hornblende. Other varieties also occur which strongly resemble this except for the absence of hornblende and a somewhat marked tendency of the plagioclase phenocrysts to lie in aggregates in a decidedly glassy base.

Another rock variety which is prominent among the breccia fragments is biotite-augite latite or andesite. This is a dark-gray porphyritic rock, with phenocrysts of biotite in flakes as much as 1 centimeter in diameter, pyroxene, and plagioclase (exceptionally as much as 1 millimeter long), in a groundmass too fine for resolution with the hand lens. The microscope shows the plagioclase to have a composition close to $Ab_{70}An_{30}$, being thus much more sodic than the phenocrysts of the biotite-hornblende andesite (latite). The pyroxene has an extinction angle of 48° and is normal augite. The rock is vesicular, with opal and a zeolite resembling phillipsite lining the vesicles. The groundmass of the rock is more glassy than in the biotite-hornblende andesite (latite). The texture is felted, with a glassy base throughout.

Hornblende-augite latites or andesites are also common as fragments in the breccia. The more abundant variety is a light-gray porphyritic rock with phenocrysts of hornblende as much as 3 millimeters long and of pyroxene as much as 1 millimeter long, with rare biotite plates as much as 5 millimeters across, set in a dense light-gray groundmass. The plagioclase has a composition close to $Ab_{70}An_{30}$. The hornblende is a brown basaltic variety, and the pyroxene is augite. The texture is felted, with a crude tendency to linear arrangement of the crystals and with very little glass in the groundmass. Analcite and a zeolite resembling phillipsite occur as secondary minerals.

Another variety of hornblende-augite andesite or latite differs from the one just described in many particulars. This is a red-brown lithoidal rock, with phenocrysts of plagioclase and hornblende, which rarely attain 1 millimeter in length, set in a dense groundmass. The microscope shows the plagioclase microphenocrysts, which rarely reach 0.5 millimeter in length, to be of calcic andesine, between $Ab_{50}An_{50}$ and $Ab_{55}An_{45}$. They show both carlsbad and albite twinning. The minute feldspars of the groundmass are more sodic, about $Ab_{70}An_{30}$. The most conspicuous mafic mineral of the rock is titaniferous augite, which occurs in beautiful euhedral crystals that rarely exceed 0.4 millimeter in length and 0.1 millimeter in diameter. Aggregates of the augite crystals are common. The pyroxene is strongly zoned, with extinction angles of 45° for the inner zone and 51° for the outer zone, measuring between Z and the *c* axis. The birefringence also varies zonally, being about 0.026 in the inner zone and 0.021 in the outer zone. The dispersion is very strong, so that there is no position of complete extinction in sections parallel to 010. The pleochroism is faint in reddish brown and yellow, with $Y>Z>X$. The cleavage is poor and in many crystals lacking. These properties indicate a titaniferous augite. Brownish hornblende occurs in fairly large crystals, which, however, are much altered to magnetite and other minerals. The hornblende is strongly pleochroic (Z, red-brown, > Y, yellow-brown, > X, pale greenish yellow). It has an extinction angle of 16°. One or two crystals of biotite occur. Natrolite and analcite occur in vesicles of the rock, and apatite and magnetite are accessories. The groundmass texture is pilotaxitic.

The rocks just described are, with the possible exception of the last, obviously all closely related and resemble the flows with which they are interbedded. Two varieties of rock, however, occur as fragments in the breccia but, as far as determined, do not appear among the main series of flows of the area. These varieties are quantitatively unimportant, but they are worthy of note as indicative of the complexity of the volcanic history of the area. One fragment is determined to be biotite-augite trachyte; the other is olivine basalt.

The trachyte is a medium-gray porphyritic rock carrying phenocrysts of biotite as much as 8 millimeters long and of pyroxene about 1 millimeter long in a dense groundmass. The microscope reveals the presence of light-greenish augite, hornblende (totally resorbed and now represented only by reaction products), biotite, and magnetite as the mafic minerals. The only feldspar determined is orthoclase, in minute prisms and carlsbad twins. If plagioclase occurs at all it must be in very minute crystals in the groundmass. No quartz was seen. The minerals just enumerated rest in a glassy groundmass constituting about 20 per cent of the rock. A partial chemical analysis shows the rock to be a normal trachyte, though the CaO content is a little high, which may mean an approach to latite, the dominant volcanic rock of the area.

The olivine basalt was not studied microscopically, inasmuch as the olivine could be determined megascopically and the rock closely resembles, both texturally and in color, a flow rock from West Canyon which has been determined as olivine basalt.

Partial analysis of trachyte and analyses of average subalkaline trachyte and latite

	1	2	3
SiO_2	62.38	63.91	57.65
CaO	5.50	2.81	[a] 5.74
Na_2O	2.68	3.08	3.59
K_2O	5.08	5.80	4.39

[a] Includes 0.16 per cent BaO and 0.07 per cent SrO.

1. Biotite-hornblende augite trachyte, fragment of breccia near head of City Canyon, Fairfield quadrangle. J. G. Fairchild, analyst.
2. Average subalkaline trachyte. Daly, R. A., Igneous rocks and their origin, p. 21, New York, 1914.
3. Average latite. Daly, R. A., op. cit., p. 23.

The breccia matrix containing the fragments of the various rocks just described is composed of finer comminuted fragments of andesitic or latitic rocks and individual crystals of feldspar and ferromagnesian minerals. In places it is structureless, but generally a faint stratification is determinable.

Origin of the breccia.—The structureless portions of the breccia may represent consolidated mud flows such as are common in volcanic eruptions, or they may be due to accumulations of volcanic bombs, lapilli, and ash; but the common interbedding of the massive breccias with definitely water-laid tuffs renders the probability of their origin as mud flows a little stronger. It is distinctly possible that the breccias are of diverse origin.

LATITE OR ANDESITE TUFFS

Beds of true tuff, whose largest fragments are smaller than 1 centimeter in diameter, are decidedly subordinate among the volcanic rocks of this field. They are prominent on the divide between Stockings Fork of Butterfield Canyon and the head of City Canyon, and also on the hill between Water Fork of Rose Canyon and the main canyon. (See pl. 8, *B*, *C*.) Such beds rarely exceed 10 to 20 feet in thickness and are commonly much thinner, being interbedded with the coarser breccias.

The fine-grained pyroclastic rocks of the area are practically all water-laid, as is indicated by their even lamination, alternation of coarser and finer layers, and arrangement of larger fragments in lenses. The tuffs are but slightly consolidated, very friable rocks, chiefly very light gray on fresh fracture but weathering various shades of green, yellow, and brown. Examination under a binocular shows the rocks to be commonly crystal tuffs, according to the nomenclature of Pirsson, but the larger fragments are of rock. Plagioclase, biotite, and hornblende are recognizable megascopically, and there can be no doubt of the close relationship of the tuffs to the interbedded breccias and flows.

LATITE FLOWS

Distribution and structural relations.—The most abundant lava in the Fairfield quadrangle is biotite-hornblende latite. From top to bottom of the volcanic series it is the dominant flow rock. It is especially prominent as forming most of the hills from Oak Spring Canyon southeastward toward Tickville Gulch. It also caps the long flat ridge followed by the boundary between Salt Lake and Utah Counties for several miles east of the head of Rose Canyon. The flow rocks predominate over the pyroclastic members in the upper part of the volcanic series. With the possible exception of the olivine basalt of West Canyon, which is not in contact with other volcanic rocks, the youngest volcanic rocks of the area are latite flows.

Lithology.—The principal variety of latite is a light-gray porphyritic rock. Clearly recognizable phenocrysts of biotite, hornblende, and plagioclase, ranging from 1 to 4 millimeters in length, are set in a dense groundmass. Flow structure is commonly conspicuous in hand specimens. Weathering results in various hues of red, brown, and purple. Under the microscope the plagioclase of the phenocrysts is seen to be faintly zoned, twinned according to the carlsbad and albite laws. Its indexes, measured by the immersion method, and its extinction angles are those of oligoclase-andesine, $Ab_{70}An_{30}$. The minute plagioclase laths of the groundmass seem to be slightly more sodic, about $Ab_{75}An_{25}$. The principal mafic mineral is hornblende, of the basaltic variety. It is chiefly in crystals from 0.2 to 0.5 millimeter long. It is strongly pleochroic (Z=Y red-brown to dark olive-brown, X light yellowish green). The extinction angle is small and variable, ranging from a maximum of 13° down to 0. The mineral is optically negative. Less prominent than the hornblende is biotite, in plates as much as 2 millimeters long. It is pleochroic (Y=Z deep red-brown, X light greenish brown) and practically uniaxial. Augite occurs in minute crystals, mostly less than 0.1 millimeter long. It is light green, with birefringence of 0.025 (from the interference chart) and extinction angles of about 45°. Apatite, zircon, and magnetite are accessories. Most commonly the groundmass is hyalopilitic, but in some specimens glass is subordinate, and the texture is to be classed as pilotaxitic. Some specimens show a development of zeolites in vesicles and partly replacing feldspar phenocrysts. Thomsonite and analcite commonly occur thus.

Variants closely related to the rock just described include biotite-augite-hypersthene latite and quartz-bearing latite that is gradational to true quartz latite. The hypersthene latite differs very little from the normal biotite-hornblende latite, being indistinguishable in hand specimens and showing in thin section the

same mineral composition as the biotite-hornblende latite save for the addition of hypersthene as the chief mafic mineral. The feldspar of the hypersthene latite is slightly more calcic than that of the hornblende latite, being close to $Ab_{60}An_{40}$.

The quartz-bearing latite is practically indistinguishable either megascopically or microscopically from the normal latite except for the sporadic quartz crystals. These are very small, and in some slides not more than two or three rounded grains, less than 0.2 millimeter in diameter, occur. They are commonly surrounded by narrow reaction rims of minute pyroxene granules. By increase in the number and size of the quartz phenocrysts, these rocks grade into true quartz latite. A partial chemical analysis of the quartz-bearing rock shows it to be a siliceous latite, with both the alkalies a trifle low but not closely approaching the percentages of the average hornblende andesite, although its silica content does.

Partial analyses of quartz-bearing hornblende latite and of average latite and average hornblende andesite

	1	2	3
SiO_2	61. 09	57. 65	61. 12
CaO	4. 70	[a]5. 74	5. 80
Na_2O	3. 00	3. 59	3. 83
K_2O	3. 77	4. 39	1. 72

[a] Includes 0.16 per cent BaO and 0.07 per cent SrO.

1. Augite-biotite-hornblende latite from Oak Spring Canyon, Fairfield quadrangle. J. G. Fairchild, analyst.
2. Average latite. Daly, R. A., Igneous rocks and their origin, p. 23, New York, 1914.
3. Average hornblende andesite. Daly, R. A., op. cit., p. 26.

None of the rocks just described carry recognizable orthoclase, and without doubt all would, in the absence of chemical analysis, be referred to the andesite group. However, partial chemical analyses reveal that potassa predominates over soda, and the conclusion seems inevitable that were the rocks entirely crystalline, potash feldspar would be a prominent constituent, comparable quantitatively to the plagioclase. Accordingly, the rocks are referred to latite.

However, latites with orthoclase crystals occur interbedded in the volcanic series toward the northern part of the Fairfield quadrangle. Inasmuch as they are megascopically indistinguishable from the latites that lack crystallized orthoclase, their occurrence may be more widespread than this statement would imply; but the only specimens recognized to be latites by the microscope alone were all obtained north of the latitude of Water Fork of Rose Canyon. These rocks are also light gray and characterized by phenocrysts of biotite, hornblende, and plagioclase in a dense groundmass. Only under the microscope is the presence of considerable orthoclase made apparent. This is reflected in the common development of microgranular texture in the groundmass, although some specimens with felted texture also carry considerable orthoclase. No potash feldspars were observed as phenocrysts. Like the latites without orthoclase crystals, some of these specimens carry strongly pleochroic hypersthene, subordinate to augite, and no basaltic hornblende. Most of the orthoclase-bearing latites, however, can be classed as biotite-hornblende latites, very like the dominant biotite-hornblende latites whose orthoclase failed to crystallize.

A partial analysis of one of the hypersthene-bearing specimens shows its close similarity to the latites that are without recognizable orthoclase, as well as to the average latite according to Daly's compilation.

Partial analyses of hypersthene-augite latite (with individualized orthoclase), augite-biotite-hornblende latite (without individualized orthoclase), and average latite

	1	2	3
SiO_2	59. 86	61. 09	57. 65
CaO	4. 62	4. 70	[a]5. 74
Na_2O	3. 31	3. 00	3. 59
K_2O	4. 84	3. 77	4. 39

[a] Includes 0.16 per cent BaO and 0.07 per cent SrO.

1. Hypersthene-augite latite from 6,589-foot hill in the southwest corner of sec. 8, T. 4 S., R. 2 W., Fairfield quadrangle. J. G. Fairchild, analyst.
2. Augite-biotite-hornblende latite from Oak Spring Canyon, Fairfield quadrangle. J. G. Fairchild, analyst.
3. Average latite. Daly, R. A., Igneous rocks and their origin, p. 23, New York, 1914.

QUARTZ LATITE FLOWS

Distribution and structural relations.—Quartz latite occurs in the lower part of the flow series in the Tickville Gulch area, lying directly on the quartzite of the Oquirrh formation about a mile west of the forks of Tickville Gulch. It also occurs near Tickville Spring, on the south slopes of South Mountain (Fairfield quadrangle), and just west of Butterfield Canyon, at the north edge of the Fairfield quadrangle. Inasmuch as quartz is rarely a very conspicuous mineral megascopically, and as except for its presence the rocks are practically identical with the latites just described, the quartz latite may be much more widespread than the foregoing statements indicate. Its similarities to the non quartz-bearing latites are so great that no attempt was made to distinguish the two varieties of lava in mapping.

Lithology.—The quartz latite strongly resembles the latites, into which, indeed, it grades. The rocks are light gray to medium gray in color, weathering to still lighter gray, cream, yellow, and brown hues. Commonly phenocrysts of biotite, hornblende, plagioclase, and a very few of quartz are recognizable megascopically. The phenocrysts reach 3 or 4 millimeters in

maximum diameter but are commonly much smaller, about 1 millimeter. The groundmass is aphanitic.

In thin section the plagioclase is seen to occur in broken and partly resorbed phenocrysts, which are twinned according to both albite and carlsbad laws and have a composition near $Ab_{70}An_{30}$ or slightly more sodic. The biotite strongly resembles that of the latite, but there is no augite in the quartz latite studied. The hornblende of the quartz latite is less basaltic than that of the latites, is pleochroic in greens rather than brown, and has extinction angles of 14°. Quartz occurs as broken and partly resorbed phenocrysts. Commonly the texture is hyalopilitic, but in some specimens it is micrographic, with individualized orthoclase and quartz developed in the groundmass.

A partial analysis of a typical specimen of this rock reveals the fact that, although there is a lack of crystallized or at least identifiable orthoclase, the rock is to be classed with the quartz latites rather than with the dacites, as is shown by the preponderance of K_2O over Na_2O. Despite the fact that some of the K_2O enters into modal biotite, there is no question that a great deal of it must be available for potash feldspar, far more than should be present in even a micaceous dacite.

Partial analyses of quartz latite and of average dacite and average mica andesite

	1	2	3
SiO_2	65. 64	66. 91	62. 25
CaO	3. 26	3. 27	4. 05
Na_2O	3. 26	4. 13	3. 55
K_2O	3. 50	2. 50	2. 44

1. Quartz latite from northwest corner sec. 2, T. 5 S., R. 2 W., Fairfield quadrangle. J. G. Fairchild, analyst.
2. Average dacite. Daly, R. A., Igneous rocks and their origin, p. 25, New York, 1914.
3. Average mica andesite. Daly, R. A., op. cit., p. 26.

A few specimens of quartz latite carry a little hypersthene, but it is nowhere the dominant mafic mineral.

Some quartz latites are recognizable as such by the microscope alone, as well-individualized orthoclase is prominent in them. Such rocks occur near Tickville Spring.

These quartz latites are light-gray porphyritic rocks carrying phenocrysts of quartz, plagioclase, biotite, and hornblende in a very fine-grained groundmass. Fluidal structure is common. The phenocrysts rarely exceed 2 millimeters in length. Under the microscope the plagioclase phenocrysts are seen to be practically all andesine, with zones ranging from $Ab_{55}An_{45}$ to $Ab_{70}An_{30}$. The quartz phenocrysts are all rounded and much embayed. The biotite and hornblende are very like the biotite and hornblende of the latites, but commonly show more alteration to iron oxide and chlorite. No augite was seen in any of the slides. Apatite and magnetite occur as accessories. Orthoclase is confined to the groundmass, of which it seems to constitute about 50 per cent. The texture of the groundmass, reflecting this high potassa content, is micrographic.

A partial analysis of a typical specimen of this orthoclase-bearing quartz latite shows a slightly less potassic composition than might be considered typical of latite, yet the potassa predominates over soda, and the rock can clearly not be classed as a dacite. Both alkalies and the silica content are lower than the average liparite (rhyolite).

Partial analyses of quartz latite from Tickville Spring and of average latite, average dacite, and average liparite

	1	2	3	4
SiO_2	66. 90	57. 65	66. 91	72. 60
CaO	2. 35	[a] 5. 74	3. 27	1. 32
Na_2O	3. 34	3. 59	4. 13	3. 54
K_2O	3. 75	4. 39	2. 50	4. 03

[a] Includes 0.16 per cent BaO and 0.07 per cent SrO.

1. Partial analysis of quartz latite from Tickville Spring, Fairfield quadrangle. J. G. Fairchild, analyst.
2. Average latite. Daly, R. A., Igneous rocks and their origin, p. 23, New York, 1914.
3. Average dacite. Daly, R. A., op. cit., p. 25.
4. Average liparite (including 40 rhyolites). Daly, R. A., op. cit., p. 19.

RHYOLITE OBSIDIAN

Distribution and structural relations.—A few small outcrops of greenish obsidian occur in both sides of Tickville Gulch, in sec. 35, T. 4 S., R. 2 W., and sec. 2, T. 5 S., R. 2 W. These exposures show the obsidian lying directly on the quartzite of the Oquirrh formation and overlain by latite flows and breccias.

Lithology.—The obsidian occurs mainly in flows and subordinately in breccias with volcanic ash. The rock is a light-greenish translucent glass with marked fluidal structure and perlitic fracture. Phenocrysts of plagioclase as much as 2 millimeters long are very numerous. No other minerals are identifiable megascopically. In thin section the plagioclase is seen to be close to Ab_{70} An_{30} in composition. Minute flakes of biotite, very small granules which are probably augite, and a few crystals of zircon are the only other minerals seen. The glass is perlitic and has a refractive index of about 1.503. The rock was classed microscopically as an andesitic obsidian, but a partial chemical analysis reveals the surprising fact that despite the prominence of the plagioclase phenocrysts, the rock has the chemical composition of a typical rhyolite—in fact, it has even lower soda and lime and higher potassa than the average.

Partial analyses of obsidian from Tickville Gulch and of average liparite and average dacite

	1	2	3
SiO_2	72. 11	72. 60	66. 91
CaO	. 71	1. 32	3. 27
Na_2O	2. 53	3. 54	4. 13
K_2O	4. 78	4. 03	2. 50

1. Rhyolitic obsidian from NE. ¼ sec. 2, T. 5. S., R. 2 W., Fairfield quadrangle. J. G. Fairchild, analyst.
2. Average liparite (including 40 rhyolites). Daly, R. A., Igneous rocks and their origin, p. 19, New York, 1914.
3. Average dacite. Daly, R. A., op. cit., p. 25.

NEPHELITE BASALT FLOW

Field occurrence.—Only one body of nephelite basalt lava was found in the Fairfield quadrangle. This occupies an area of a few acres in the NE. ¼ sec. 31, T. 4 S., R. 2 W., capping a small knoll on the east flank of Sheep Ridge. At the north the nephelite basalt overlies latite breccia, but at the south end of the small outcrop it overlaps the breccia onto the quartzite of the Oquirrh formation.

Lithology.—The nephelite basalt is a very heavy rock, of dark-brown to almost black color. It is porphyritic, with phenocrysts of brown mica about 2 or 3 millimeters in diameter and of olivine about 1 millimeter in diameter set in a dense groundmass.

Under the microscope the dominant phenocrysts are seen to be olivine and a pale variety of biotite in about equal amounts, together making up about 20 per cent of the rock. The olivine crystals are euhedral, ranging from about 1 millimeter down to about 0.2 millimeter in length in seriate porphyritic fashion. The olivine is optically positive, with large axial angle and birefringence about 0.034. The biotite is a beautifully pleochroic variety, with X very pale yellow and Y=Z light rosy brown, with a striking golden luster. It is twinned on the face 001 and shows inclined extinction of 4°. Its birefringence is about 0.035. The biotite crystals are anhedral and poikilitically inclose great numbers of subhedral augite crystals, most of which are very small—less than 0.05 millimeter long and grading down to the limits of the microscope. Some of the augite crystals, however, attain lengths of 0.3 millimeter. They are colorless, nonpleochroic, with extinction angles of 40° and birefringence of about 0.025. Probably 35 or 40 per cent of the rock is composed of augite. No feldspar occurs in the rock, the groundmass being composed of a mat of nephelite and augite crystals nearly all less than 0.05 millimeter long. The nephelite has the characteristic short, stumpy prisms of hexagonal cross section where cut at right angles to the axis and rectangular section parallel to the axis. It has indexes equal to or slightly higher than that of canada balsam, negative elongation, parallel extinction, and very low birefringence, so that the determination as nephelite is assured.

OLIVINE BASALT FLOW

Distribution and structural relations.—A small remnant of a flow of olivine basalt occurs on the south side of West Canyon just below the mouth of Iron Canyon. Except for a few fragments in the latitic breccia, this is the only feldspar basalt in the Stockton and Fairfield quadrangles. It is not in contact with any other volcanic rock, but its topographic situation suggests that it may possibly be the youngest volcanic rock of the area. However, it is perhaps equally possible that its position is accounted for by the exhumation of a prevolcanic valley and that the flow is older than the bulk of the extrusives.

Lithology.—The rock composing the West Canyon flow is a dark greenish-gray amygdaloid. The only minerals recognizable in hand specimens are olivine and feldspar. The amygdules are filled with opal and zeolites.

In thin section the rock is seen to contain microphenocrysts of olivine as much as 1 millimeter long and of augite as much as 1.5 millimeter long, commonly in aggregates resembling phenocrysts. The augite is less than 0.1 millimeter in minimum grain size. It has a pale-green color, a birefringence of about 0.025, and an extinction angle of about 45° and is optically positive. The olivine is in rounded to subhedral grains showing the characteristic rough cleavage and alteration to light-greenish serpentine. Plagioclase occurs in laths as much as 0.4 millimeter long. It has a composition close to $Ab_{50}An_{50}$. Magnetite is a conspicuous accessory, and apatite is also present. A small amount of glass occurs in the base, and the texture of the groundmass, though chiefly intersertal, varies locally to pilotaxitic. The zeolites in the amygdules are chiefly phillipsite, with n less than 1.51 and greater than 1.50, low birefringence, and extinction angles of 32°. The estimated mineral composition of the rock is as follows:

	Per cent
Plagioclase	58
Augite	25
Olivine	8
Serpentine	5
Magnetite	3
Apatite	1

INTRUSIVE ROCKS

The intrusive rocks of the Stockton and Fairfield quadrangles, including granular rocks and porphyries, are prevailingly monzonitic but range from diorite through monzonite to granodiorite and quartz monzonite and their corresponding porphyries. However, rhyolite and andesite (or latite) are present, and a

few small bodies of nephelite basalt and lamprophyre are likewise found.

MONZONITE AND RELATED ROCKS

SUBDIVISIONS

The monzonite and related rocks have a considerable range in composition, but despite the variations the rocks appear to be very closely related genetically and are conveniently grouped together, although the local variations are sufficient to justify separate descriptions of the larger bodies. For this reason, these rocks will be discussed in groups according to their geographic distribution.

PORPHYRY KNOB AND LION HILL

The intrusive rocks on Porphyry Knob and Lion Hill were given the miner's name "Bird's-eye" porphyry by Spurr.[28] These localities are in the northern portion of the Mercur mining area.

Distribution and structural relations.—The occurrences of the "Bird's-eye" porphyry of Spurr are isolated from the other intrusions of closely comparable character and are grouped in the vicinity of Porphyry Knob and Lion Hill. Fourteen separate masses were mapped, all of which have general sill-like relations although they may be more irregular in detail; but exposures at and near the contacts are too poor or too few to permit detailed mapping.

Where well exposed (as on Porphyry Knob and on the larger mass west of Porphyry Hill) the intrusive rocks exhibit two prominent sets of joint planes which intersect in a direction roughly normal to the stratification of the inclosing limestones. Locally one set is better developed than the other, giving rise to a slabby or sheeted appearance. Where the sets are about equally developed a rude columar structure becomes evident.

A number of small faults cut the sill of Porphyry Knob, but they are of slight displacement and have no apparent control of the distribution of the igneous rock.

The thickest sill, that outcropping on the west slope of Porphyry Hill, is over 400 feet thick, but none of the other sills of "Bird's-eye" porphyry exceed a few tens of feet. The sills on Lion Hill appear to have exercised some control of the ore deposition, for the jasperoid that carries the ore seems to lie immediately beneath one of the sills. The writer concurs in the opinion of Butler[29] that this sill, as well as all the others on Lion Hill, is to be referred to the "Bird's-eye" (monzonite) porphyry rather than to the Eagle Hill rhyolite, as was suggested by Spurr.[30] Two sills of this rock, each only a few feet thick, are cut by the Buffalo tunnel, on the east flank of Lion Hill, but here there is no apparent relation between the igneous rock and the ore bodies.

Lithology.—The "Bird's-eye" porphyry is very poorly exposed, and its exposures are very much altered, either by weathering, as in most outcrops, or by the action of hydrothermal solutions related to ore deposition, as in most of the exposures on Lion Hill. For this reason it is difficult to obtain satisfactory material for study.

The freshest material seen is a medium-gray porphyritic rock with numerous phenocrysts of feldspar, biotite, hornblende, and quartz in a greenish-gray groundmass of which the constituent minerals are unrecognizable. Where more decidedly weathered the rock has a lighter cast, the feldspar crystals contrast less strongly with the groundmass, and the biotite assumes a bronzelike luster. Hydrothermal alteration has resulted in a very light-gray rock with dull-white feldspar, only faint buff pseudomorphs after biotite, and a pyrite-bearing groundmass of light-gray hue.

The feldspar phenocrysts in the rock all appear to be plagioclase. They range from about 1 millimeter to about 6 millimeters in size. The biotite occurs in barrel-like hexagonal tablets which reach about 3 millimeters in length. Hornblende is less conspicuous, although a few crystals with typical amphibole cleavage and greenish-black color are recognizable. They are chiefly less than 2 millimeters long. Quartz is not a conspicuous mineral among the phenocrysts, but occurs in rounded grains 2 or 3 millimeters in maximum diameter.

Under the microscope the rock is seen to be seriate porphyritic with respect to the feldspar crystals, which range from 6 millimeters in length down to less than 0.1 millimeter, without sharp discontinuity in size range. The larger feldspar phenocrysts appear to be well-formed, equant, and somewhat zoned and show both carlsbad and albite twinning. Their composition is close to $Ab_{60}An_{40}$. The smaller crystals are slightly more sodic, about $Ab_{65}An_{35}$.

The quartz phenocrysts are much resorbed and exhibit no crystal faces. They are considerably fractured and show deep embayments of groundmass. Orthoclase phenocrysts are subordinate, although a few well-formed crystals as much as 1 millimeter in diameter occur. Biotite is largely altered to chlorite, but some still remains unaltered. It originally formed crystals of clear-cut outlines as much as 3 millimeters long. Apatite is conspicuous, some crystals approximating 1 millimeter in diameter. No hornblende occurs in the two slides of this rock that were studied, but without

[28] Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, pp. 379–380, 1895.

[29] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 381, 1920.

[30] Spurr, J. E., op. cit., p. 379.

question it is sparingly present. Pyrite and probably magnetite also occur in small amounts.

The groundmass of the specimens studied is much clouded with alteration products but is evidently composed chiefly of quartz and orthoclase in microgranitic arrangement. The grain size of the constituent minerals averages perhaps 0.05 millimeter. Among the phenocrysts the plagioclase predominates over orthoclase in about the ratio of 10 to 1. This proportion is reversed in the groundmass.

Classification.—The rock is completely crystalline and porphyritic, with total plagioclase predominating over total orthoclase in a ratio somewhat greater than 2 to 1. As quartz is an essential constituent, the rock falls into the class of granodiorite porphyries. The "Bird's-eye" porphyry is the only granodioritic rock found in the Stockton-Fairfield area, but its relation to the more potassic monzonites farther north is doubtless very close.

SOLDIER CANYON

Distribution and structural relations.—The largest intrusive mass within the Stockton and Fairfield quadrangles crops out high on the north wall of Soldier Canyon in secs. 28 and 27, T. 4 S., R. 4 W. This body is a stocklike mass approaching quartz monzonite in composition. Its contacts are crosscutting, despite the fact that its major axis lies roughly parallel to the strike of the country rock and apparently reflects a notable amount of control of the intrusion channel by the preexisting structure. Toward the south and east of this stock are a number of dioritic and monzonitic sills, evidently closely related to it and extending for about 3 miles along the strike. Most of these sills are of slight thickness, and the largest is only about 30 feet thick. In addition to these dioritic and monzonitic sills there are a few thin sills of andesite and one of dacite in this area. They are mapped with the monzonite sills. All these bodies except the large mass first mentioned are accordant with the structure of the sedimentary rocks in which they lie but show local minor discordances.

Lithology and classification of quartz monzonite stock.—The dominant variety of the rock composing the Soldier Canyon stock is a medium-gray equigranular millimeter-grained rock which contains quartz, plagioclase, orthoclase, biotite, and pyroxene recognizable in the hand specimen. There is a slight tendency for aggregates of pyroxene crystals to form pseudophenocrysts, but otherwise the rock possesses no unusual features.

Locally along the border of the mass the rock is decidedly more coarse grained and feldspathic than it is in the middle. The quartz, orthoclase, and plagioclase form a light-gray rock speckled with bright-green pyroxene crystals 2 to 3 millimeters in length. Pyrite is also present in veinlets through this rock. Elsewhere the stock possesses no unusual mineral development at the border.

In thin section the normal facies of the rock exhibits granitic texture. Plagioclase occurs in fairly well-formed crystals which range in size from 0.1 to 2 millimeters and average between 0.3 and 0.5 millimeter. There is very little zonal development, and the composition is about $Ab_{70}An_{30}$ (oligoclase-andesine). Microcline, one of the last minerals to crystallize, is largely anhedral, but a few of its crystals are rather well formed and are nearly 1 millimeter long. Plagioclase and orthoclase occur in about equal amounts and together constitute about two-thirds of the whole rock. Quartz, which makes up about 15 per cent of the rock, is anhedral, like the orthoclase.

The most prominent mafic mineral is light-green diopside, which occurs in well-formed crystals about 1 millimeter in greatest length. It is accompanied and in part replaced by biotite and to a less extent by magnetite. A small amount of light-green pleochroic uralitic hornblende is also developed. Biotite occurs along cracks and borders of the diopside and in independent euhedral plates which reach 1.5 millimeters in diameter. In part it is replaced by magnetite through magmatic reactions. Original magnetite, apatite, and titanite are minor accessory minerals.

The coarser border facies differs from the normal rock in having its plagioclase subordinate to the microcline in about the ratio of 2 to 5. The pyroxene also shows somewhat more alteration to uralitic hornblende than that in the normal rock. No biotite is present in this variety. Small nodules and angular fragments of calcite, which probably represent residual xenoliths of country rock, are present. There is a suggestion, which may readily be exaggerated, that the diopside is more plentiful in the neighborhood of such inclusions, an expectable association but one which it would be difficult to establish in the specimens studied. The rock is very fresh, and the calcite can not be attributed to weathering.

The texture of this rock is not a simple granitic one but possesses analogies to the "sieve structure" of Grubenmann,[31] in which the several minerals inclose one another. This texture he attributes to sudden crystallization of a supersaturated solution. It is possible that rapid growth of crystals leading to mutual inclosures might be induced by subsequent "seeding" of a slightly supersaturated magma solution—a seeding which might occur through the picking up of xenoliths. The consequent rapid consolidation may be the cause of the lack of biotite as a reaction product of the diopside.

[31] Grubenmann, U., and Niggli, P., Die Gesteinsmetamorphose, p. 420, Berlin, 1924.

The principal facies of the Soldier Canyon stock, containing plagioclase and microcline in essentially equal amounts and plentiful quartz, is a normal quartz monzonite. The border facies studied, with its microcline-plagioclase ratio of about 5 to 2, would be classified by Johannsen as a quartz syenomonzonite, but most writers would class it as a granite. It is quantitatively unimportant.

Lithology and classification of sills.—The sills that crop out on the north wall of Soldier Canyon are obviously closely related to the stock, though varying considerably among themselves. They are all shown on the geologic map as "quartz monzonites and related rocks," but, as will be seen from the descriptions below, they range from quartz monzonite porphyry to diorite.

The sills, which roughly parallel the southern contact of the stock, at a distance of a few score feet, are coarsely porphyritic rocks. The prominent phenocrysts are plagioclase and sanidine, reaching 1 centimeter in length and averaging well over 5 millimeters. They are accompanied by much smaller quartz phenocrysts, few of which exceed 2 millimeters in diameter, and small biotite crystals and are set in a dense groundmass. The rock is much altered and stained brown through weathering. Under the microscope the only minerals identifiable are oligoclase-andesine, of about the composition $Ab_{70}An_{30}$, sanidine, quartz, biotite largely altered to chlorite, apatite, and magnetite. The oligoclase occurs in well-formed but highly weathered and cloudy phenocrysts about 2 millimeters in length. The sanidine is almost uniaxial, with extinction angle 9° between α and 001. The phenocrysts range from 1 centimeter to 1 millimeter and average about 4 millimeters. The quartz occurs in much resorbed crystals about 2 millimeters in maximum diameter. The biotite is almost all altered to a nearly colorless chlorite and iron rust. Apatite and magnetite are accessories. The phenocrysts altogether constitute about 40 per cent of the rock and include roughly equal amounts of plagioclase and sanidine with much less quartz and biotite. They are set in a microgranitic groundmass which is much clouded with weathering products. These characteristics permit the classification of the rock only as a quartz monzonite porphyry. Rocks resembling it very closely are common in the Stockton mining area.

Several of the Soldier Canyon sills can be described as diorite porphyry. These rocks are medium to dark gray and more or less altered. They contain recognizable phenocrysts of hornblende and plagioclase and, in some specimens, of biotite and epidote in a dense groundmass. The microscope shows them to consist of much altered plagioclase phenocrysts which reach 2.5 millimeters in length, hornblende, and a very little quartz, with apatite and magnetite as minor accessories. The plagioclase is sodic andesine, with a composition of about $Ab_{65}An_{35}$. Some specimens carry a small amount of augite as phenocrysts which show alteration in hornblende; others carry no pyroxene but considerable epidote of the variety pistacite. The epidote is probably to be referred to hydrothermal alteration related to ore deposition. Orthoclase is subordinate and is confined to the groundmass. The groundmass makes up more than half of the rocks examined and is much altered to a mass of calcite, clay minerals, and quartz. The texture is seriate porphyritic with microcrystalline groundmass, and the rocks are to be classed as diorite porphyries.

Fine equigranular medium-gray rocks which are referred to diorite also occur as sills, both closely associated with the Soldier Canyon stock and half a mile or so to the southwest of it. These rocks carry megascopically recognizable biotite, amphibole, and plagioclase. Under the microscope the rocks are seen to be fine grained, of granitic texture, with predominant plagioclase in crystals about 0.1 to 0.3 millimeter long, biotite, hornblende (or, in some rocks, uralitic amphibole), and subordinate orthoclase with a small amount of interstitial quartz and accessory apatite and magnetite. The rocks are altered both by magmatic reactions, leading to the breaking up of the mafic minerals to yield magnetite, and by weathering, which has produced a very cloudy appearance in the feldspar and considerable halloysite and presumably other clay minerals. The plagioclase is strongly zoned, the center of some crystals being about $Ab_{45}An_{55}$, whereas the border is close to $Ab_{80}An_{20}$. The average composition is doubtless not far from $Ab_{70}An_{30}$. The rocks are to be classed as fine-grained biotite-hornblende diorites.

One sill of quartz diorite porphyry was found low on the north wall of Soldier Canyon in sec. 33, T. 4 S., R. 4 W. This rock resembles the diorite last described except for the presence of very large phenocrysts of biotite and feldspar, which reach 5 millimeters or even 1 centimeter in length, in a groundmass resembling the equigranular diorite just described. Quartz is more prominent than in the nonporphyritic rock, and the specimens available to study are much more weathered and calcitized; otherwise the rock is very like the equigranular diorite.

High on the wall of Soldier Canyon in the southern part of secs. 26 and 27, T. 4 S., R. 4 W., is a sill which is composed of porphyritic medium-gray rock carrying conspicuous phenocrysts of plagioclase, biotite, and pyroxene in a fine-grained groundmass. The plagioclase crystals reach 6 millimeters in length, the biotite 3 or 4 millimeters, and the pyroxenes about 2 millimeters. The microscope reveals a seriate porphyritic, completely crystalline rock. Plagioclase (zoned,

$Ab_{65}An_{35}$ to $Ab_{75}An_{25}$, the more sodic zones toward the exterior) occurs in well-formed crystals that range from less than 0.1 millimeter to 6 millimeters in size. It makes up nearly 40 per cent of the rock. Orthoclase, though occurring in smaller crystals and largely as anhedral interstitial grains, is fully as abundant. The pyroxene is common augite of a light-green hue, nonpleochroic, and reaching 2 millimeters in size but averaging perhaps 0.2 millimeter. It is partly altered to biotite, which is also independently developed. The biotite has normal pleochroism and where it is clearly a reaction product of pyroxene is accompanied by conspicuous magnetite. There is a small amount of common hornblende, pleochroic in green and greenish brown (Z=Y>X) and with extinction angle of 25°. Apatite and magnetite are conspicuous accessories. The quartz is all interstitial and can hardly exceed 5 per cent of the total rock. The groundmass is of granitic texture, with an average grain of about 0.05 millimeter. The rock is best described as a monzonite porphyry.

In the SW. ¼ sec. 36, T. 4 S., R. 4 W., is a sill of biotite dacite which can be traced for a few hundred feet. It is strictly accordant with the structure of the inclosing rocks, as far as can be judged from the discontinuous exposures. Its thickness hardly exceeds 20 feet. The microscope reveals a rock of trachytic texture consisting of sparse phenocrysts of feldspar, biotite, and quartz set in a groundmass composed almost wholly of feldspar laths. These feldspar laths are very small, mostly less than 0.1 millimeter long, and from their indexes are presumably calcic oligoclase, about $Ab_{75}An_{25}$. A very little orthoclase, a considerable amount of quartz, and some minute biotite flakes also occur in the groundmass. Zircon and apatite are accessory. Considerable alteration has occurred and the rock studied has been impregnated with a good deal of calcite. The mineral composition and texture of this rock are such as to classify it as a biotite dacite. It does not closely resemble any of the other rocks of the area, but there is no reason to doubt that it is a derivative of the magma whose dominant representatives are dioritic and monzonitic rocks.

The longest sill exposed in Soldier Canyon is composed of andesitic rock. It can be followed from a point near the center of sec. 35, T. 4 S., R. 4 W., in a west-northwesterly direction nearly to the middle of the south line of section 28. The sill is about 20 feet in average thickness and conforms to the structure of the country rock as far as the relations are revealed by the rather poor exposures.

The rock composing this sill is a light-gray porphyry. The only minerals identifiable in the hand specimen are hornblende and feldspar, both much altered. A trachytic texture is apparent. In thin section the feldspar is seen to be chiefly in small laths with a composition near $Ab_{60}An_{40}$. Hornblende and possibly biotite are represented by iron-stained pseudomorphs of calcite, and the feldspathic constituents are likewise much altered to calcite and cloudy aggregates of clay mineral. The rock is an andesite, doubtless related to the diorites and monzonites of the neighboring sills.

STOCKTON AREA

Distribution and structural relations.—In and near the mining area of Stockton there are many dikes, sills, and small stocks, chiefly of quartz monzonite porphyry, with some closely related rocks, such as diorite porphyry. In the southern part of this district, in secs. 29 and 30 and the southern part of sec. 20, T. 4 S., R. 4 W., most of these igneous bodies are in the form of small, irregular transgressive stocks, although a few dikes occur. Farther north, in sections 17, 18, 19, and 20, the intrusive rocks occur chiefly as northward-trending, westward-dipping dikes, although a few sills were seen in the workings of the Honerine mine.

The parallelism of these dikes to numerous faults in this area suggests strongly that most of them have been intruded along preexisting fault fractures. Considerable brecciation of wall rock along one or two of the dikes strengthens this suggestion, although the brecciation may have been due to the forcible intrusion of the dikes instead of to earlier faulting. Although a certain amount of postporphyry faulting has occurred in this area, there is no likelihood that the brecciation can be attributed to this late period.

The largest intrusive mass near Stockton is the stocklike body known locally as the "Raddatz" porphyry, because it was first cut by mine workings under the supervision of Mr. Raddatz. This mass is very inconspicuous at the surface, near the Honerine air shaft, but widens considerably in depth and where cut on the 1,200-foot level of the Honerine mine is 300 feet wide. This and the other stocklike masses farther south are in contrast with the narrower dikes in having notable contact zones about them, whereas the metamorphosing effects of the smaller bodies on the country rock are much less pronounced. The metamorphosing effects of the intrusions are discussed in detail in a later section of this report.

North of Selkirk Canyon, not far outside the mineralized area of Stockton, are two sills which resemble, in general, the intrusive rocks of the Stockton area and can be conveniently discussed at this point. These sills are rather conspicuous. The eastern one is only a few feet thick but is traceable for well over a mile, and the western one is about 100 feet thick and forms a prominent light-gray band across the mountain

spurs just above the alluvium. Both conform closely to the bedding of the country rock.

Lithology of the quartz monzonite.—The commonest intrusive rock of the Stockton area is quartz monzonite porphyry. Several variants of the rock occur, distinguished chiefly by their grain size. Of these variants the most abundant, which closely resembles the first-described group of sills associated with the Soldier Canyon stock, is a medium-gray porphyry that carries very conspicuous pink orthoclase, less prominent quartz, plagioclase, biotite, and hornblende as phenocrysts in a dense groundmass. The orthoclase phenocrysts range from 5 millimeters to 1 centimeter in average length. Plagioclase occurs in lathlike crystals, rarely exceeding 3 millimeters in length. The quartz phenocrysts are rounded, do not exhibit crystal faces, and rarely exceed 2 millimeters in diameter. The biotite plates are about 1 millimeter long, and the hornblende of about the same size. Many of the specimens show mottling of the feldspars by epidote. In thin section the rock is seen to consist of about 50 per cent phenocrysts and 50 per cent microgranitic groundmass, with an average grain of about 0.05 millimeter in the better-crystallized specimens and somewhat smaller in the less well crystallized. The orthoclase phenocrysts are commonly twinned according to the carlsbad law and are euhedral. Plagioclase, which is about equal in amount to the orthoclase, is commonly twinned according to both albite and carlsbad laws. Its composition is that of sodic andesine, slightly more calcic than $Ab_{70}An_{30}$. A very little pyroxene, probably augite, occurs in some specimens, but most of it has been altered to biotite and amphibole. Biotite shows no unusual characters. Hornblende is not present in all the specimens examined but where present is pleochroic in green and brown, with extinction angles between 16° and 22°. Epidote is commonly present in the mineralized areas, probably as a result of the action of hydrothermal solutions on the consolidated rocks. It replaces the mafic minerals and both feldspars. It is chiefly pistacite, although considerable clinozoisite also occurs. Both hornblende and biotite, as well as epidote, are altering to chlorite because of weathering. The quartz phenocrysts are much resorbed and exhibit rounded outlines and some fracturing. Apatite, zircon, magnetite, and a little titanite are common accessories, and the more epidotized specimens also carry pyrite, which is presumably epigenetic. Sericite in small amounts is a common replacement product of feldspar. Some of the much-weathered specimens show calcite. In most of the specimens examined orthoclase predominates slightly over the plagioclase, but nowhere to the extent that might be expected from the megascopic prominence of the orthoclase.

The commonest variants from the type of rock just described are distinguished chiefly by the large size of their orthoclase phenocrysts. The "Raddatz" porphyry and the two sills north of Selkirk Canyon are especially conspicuous in this respect. The rocks of these bodies carry orthoclase phenocrysts fully 1.5 centimeters in average length, and many of the crystals are as much as 3 or 4 centimeters long. Most of these large phenocrysts are beautifully euhedral. Sharply bounded simple crystals and carlsbad twins 2 and 3 centimeters in length can be found in profusion on weathered outcrops. Microscopically these varieties do not differ notably from the dominant rock except that they contain few orthoclase crystals intermediate in size between the large phenocrysts and the groundmass. Thus, although the orthoclase is decidedly more conspicuous in these rocks than in the common type, it is probably not more abundant.

Varieties of finer grain than the main type also occur, but beyond the difference in grain size and correspondingly less conspicuous porphyritic texture, they possess few noteworthy features.

Lithology of minor related types.—A few of the intrusive rocks of the Stockton mining area are to be classified as monzonite porphyry, diorite porphyry, and quartz diorite porphyry, although they are included on the geologic map with the quartz monzonites under the somewhat elastic phrase "quartz monzonites and related rocks."

A few bodies of fine-grained monzonite porphyry crop out near the Calumet mine. They are chiefly small dikes and irregular pluglike bodies of medium-gray rock. They differ from the common facies of quartz monzonite porphyry only in their much smaller grain size, few of the phenocrysts reaching 1 millimeter in length, and in the absence of quartz among the phenocrysts. Even the groundmass carries very little quartz, estimated at well under 5 per cent.

In the mines of Stockton dikes of highly altered dark greenish-gray rock occur. One of these, on the 1,000-foot level of the Ben Harrison mine just east of the shaft, carries 1-millimeter phenocrysts of hornblende, plagioclase, quartz, and chloritized biotite in a dense groundmass. Alteration has been intense, but the microscope reveals the absence of orthoclase as phenocrysts and its subordinate importance in the groundmass. The rock is an altered quartz diorite porphyry.

Several dikes in the Honerine mine, especially in the Weir crosscut and the 1650 north crosscut, are dark greenish-gray porphyry which the microscope shows to be diorite porphyry. These rocks are characterized by andesine in phenocrysts 1 millimeter long and in the microlitic groundmass, uralitic hornblende containing small pyroxene remnants, common hornblende, chlorit-

ized biotite, serpentine, and small amounts of quartz and orthoclase, both of which are confined to the groundmass. Sericite and chlorite are prominent, and some of the quartz may be due to hydrothermal silicification. The original rocks were without doubt to be classed as diorite porphyry.

SETTLEMENT AND MIDDLE CANYONS

Distribution and structural relations.—Owing to the cover of vegetation and talus, exposures are very poor in both Settlement and Middle Canyons, so that there are probably a number of igneous bodies there which escaped detection. However, it is probable that any such bodies are small. An isolated sill occurs on the north slope of Settlement Canyon just below the mouth of Dry Fork; a group of small stocks and associated sills occur in the valley of the east fork of Settlement Creek and extend over the divide into White Pine Flat; a small stock crops out in the north wall of Middle Canyon just below the mouth of White Pine

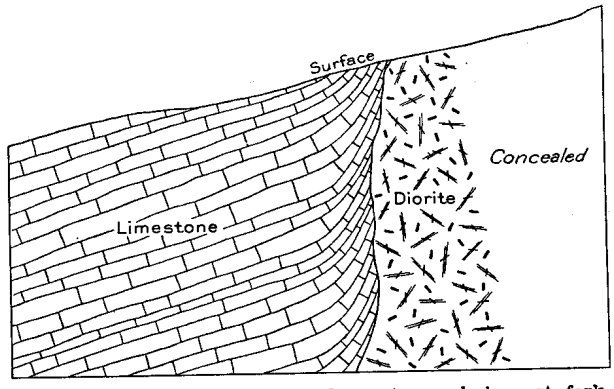


FIGURE 7.—Relations of dike and country rock in east fork of Settlement Canyon, showing deformation of the country rock, presumably by the force of igneous intrusion

Canyon; and a number of small dikes occur on the extreme edge of the Fairfield quadrangle north of this stock. Besides these bodies a specimen of andesite was found on the dump of a caved prospect tunnel a few hundred yards east of the Middle Canyon portal of the Utah Metal Co.'s tunnel, but no exposure of the rock in place could be discovered.

The structural relations of most of these bodies are sufficiently summarized by their classification as sills, stocks, and dikes, but the relations of one dike are of sufficient interest to warrant description as demonstrating the powerful intrusive force of the magma. This dike is an offshoot of the westernmost stock in the east fork of Settlement Canyon, and its exposed part extends upward from the main stock as a cross-cutting body some 20 feet wide. The east wall of the dike is concealed, but the west wall is formed by thin-bedded limestone of the Oquirrh formation. Where these limestones abut against the dike they are bent from their normal westward dip of about 30° nearly to the vertical, the displacement of the end of a given bed amounting to several tens of feet. There is no suggestion of postigneous faulting, and it is difficult to escape the impression that very powerful injection forces have caused the emplacement of the dike. The relations are illustrated by Figure 7.

Lithology.—The sill exposed northwest of the mouth of Dry Fork of Settlement Canyon is of quartz monzonite porphyry, so nearly resembling the sills north of Selkirk Canyon just described and the "Raddatz" porphyry of the Honerine mine that it was not studied microscopically. It contains very large orthoclase phenocrysts with smaller ones of quartz and plagioclase.

The stocks in the east fork of Settlement Canyon and extending over the divide into White Pine Canyon are composed of dioritic rock in its various facies, light, medium, and dark gray. Most specimens are equigranular, but in places the border facies of the stocks are porphyritic. Biotite, pyroxene, and plagioclase are recognizable in all specimens, and a few show quartz in addition.

The more mafic equigranular facies are shown by the microscope to have granitic texture, with the grain size of the plagioclase averaging about 0.5 millimeter and that of the mafic minerals somewhat larger. The principal constituent is plagioclase, which makes up about 50 per cent of the rock. It occurs in ragged-ended laths, twinned according to both carlsbad and albite laws. Its composition is close to $Ab_{60}An_{40}$ (andesine). Orthoclase is subordinate, not exceeding 10 per cent of the rock, and is chiefly interstitial, although in sporadic euhedral crystals. Pyroxene makes up more than 20 per cent of the rock and occurs in aggregates forming pseudophenocrysts and as isolated euhedral crystals. It is a light-green, nonpleochroic augite, with some zoning. It shows alteration by magmatic reactions in two ways—to amphibole, pleochroic in green and brown, and more commonly to biotite. The alteration to biotite is controlled by the cleavage of the augite to a slight extent, but more of the biotite appears to be developed parallel to a steep end face of the host mineral. Biotite also occurs in well-individualized plates as much as 2 millimeters long. Apatite, titanite, and magnetite are accessories. One of the striking features of the rock is the presence of narrow veins of zeolites, chiefly analcite and thomsonite, which cut through the rock. The zeolites also replace the plagioclase feldspar to a notable extent. This facies of the rock is to be classed as a biotite-augite diorite.

The more felsic equigranular facies of the rock is somewhat finer grained and is composed of the same minerals as the mafic facies, except that it contains only about 20 per cent of dark minerals, the difference being made up by quartz and analcite. The texture

of the rock is also decidedly different from that of the mafic facies. The feldspar laths are disposed in a divergent mesh suggesting the texture of a lamprophyre, but the mafic minerals are far less abundant and less well crystallized than they should be for a true lamprophyric rock. Magmatic reactions have decidedly frayed the augite crystals, and there has been more development of uralitic hornblende than of biotite after augite, although biotite does occur in this manner. The small amount of biotite independent of augite is less well formed than in the mafic rock. There is a more striking association of magnetite with the dark minerals than in the darker facies. The plagioclase is more calcic in this facies, being about $Ab_{50}An_{50}$. Quartz is chiefly interstitial but occurs also in grains as much as 0.2 millimeter in diameter. Zeolitization of the feldspar has been intense. The chief zeolite present is analcite. The rock is analcitized quartz-augite diorite.

A third variant of the Settlement Canyon stocks is the porphyritic contact rock mentioned above. This rock exhibits phenocrysts of hornblende as much as 1 centimeter long and of biotite about 2 millimeters long, set in a medium-gray groundmass in which plagioclase is the only megascopically identifiable mineral. Under the microscope the phenocrysts are seen to be hornblende, pyroxene, and biotite. The hornblende is pleochroic in green and dark brown ($Z=Y>X$). It is optically negative, with an extinction angle of 25°. It is corroded about the borders, with the development of a nearly continuous inner zone of magnetite and an outer rim of biotite about each crystal. Augite is also developed in these zones. Some of the augite is in a few poorly formed phenocrysts as much as 1 millimeter long which show a tendency to occur in aggregates, but most of it occurs as granules through the groundmass. Biotite phenocrysts as much as 2 millimeters long occur in addition to the reaction rims around the hornblende and a few small wisps developed in association with the augite. Plagioclase, with composition close to $Ab_{50}An_{50}$, occurs in laths and tables as much as 1 millimeter long but mostly less, and considerable plagioclase occurs as granules interstitial to the other minerals. Orthoclase is a very subordinate mineral, not exceeding 10 per cent of the rock. It is wholly interstitial. A little quartz may be present with the orthoclase. Magnetite and apatite are accessories. The texture of the rock is very unusual. Areas of coarser crystallized plagioclase and mafic minerals are set in a fine-textured groundmass composed of granules of plagioclase, augite, biotite, orthoclase, and possibly quartz. There are "log-jam" arrangements of plagioclase laths around the larger mafic phenocrysts, and the groundmass shows in places a micropoikilitic texture.

A short distance south of the stock that crops out east of the main divide of the mountains, between White Pine Flat and Settlement Canyon, are a few thin sills. Most of these are much weathered, brown-stained fine-grained rocks. Under the microscope the rock is seen to be a highly analcitized andesite, containing biotite plates and plagioclase laths ($Ab_{65}An_{35}$) showing flow structure, in a fine-grained, felted groundmass which may contain a little orthoclase. Analcite has replaced much of the feldspar. A sill of similar rock occurs in the north flank of the 9,245-foot peak just north of this stock, but it was not examined microscopically.

The stock cropping out on the north wall of Middle Canyon just below White Pine Canyon is composed of a handsome medium-gray porphyry. The phenocrysts include orthoclase, plagioclase, biotite, and hornblende, of which all but the orthoclase are only slightly more than 1 millimeter long. The orthoclase crystals, however, reach or even exceed 1 centimeter in length. The microscope shows the plagioclase to be a calcic oligoclase, about $Ab_{75}An_{25}$, twinned according to both carlsbad and albite laws. It makes up about a third of the rock, mostly as phenocrysts. Orthoclase, despite the greater size of its crystals, is not so abundant among the phenocrysts but makes up nearly or quite half the entire rock. It forms beautiful carlsbad twins, much resembling those of the Stockton mining area. Biotite is the most conspicuous dark mineral but exhibits no noteworthy features beyond its euhedral character. The rock contains a little pale-green, nonpleochroic augite and a very little hornblende, pleochroic in green and brown. Quartz occurs in broken phenocrysts 1 millimeter in diameter and forms about 5 per cent of the groundmass. Apatite, magnetite and titanite are accessory, and a little calcite, doubtless due to weathering, completes the list of minerals determined. The texture of the rock is seriate porphyritic, with respect to the feldspars. The groundmass textures range from granitic to micrographic, with the former predominant.

TICKVILLE GULCH

Distribution and structural relations.—There is a small mass of dioritic rock near the center of sec. 26, T. 4 S., R. 2 W., in a tributary to Tickville Gulch. It is indicated on the geologic maps as about 500 feet north of the plug of Tickville rhyolite breccia. The mass is a small plug, only about 100 to 150 feet wide, intruding the Oquirrh formation and a quartz latite flow belonging to the volcanic series of the Traverse Mountains. This fact is of considerable interest, because this locality is the only place in the Stockton and Fairfield quadrangles where volcanic and coarse intrusive rocks are in contact and shows that this par-

ticular plug is younger than the volcanic rocks of the Traverse Mountains. This relation is commented on further in the section dealing with the age of these rocks. As will appear on its description, the rock of this plug is decidedly aberrant and possibly is not closely related to the monzonitic and dioritic rocks previously discussed; however, the assumption of contemporaneity seems reasonable.

Along the tributary in which this small plug crops out, and only about 200 yards below it, occurs a small exposure of diorite porphyry whose relations are obscure. The contacts with the alluvium and volcanic rocks are concealed by talus, and nothing was learned of either the extent or the shape of the body. Presumably, however, it is related to its better-exposed neighbor and, like it, is intrusive in the volcanic series of the Traverse Mountains.

Lithology.—The rock of the small, well-exposed plug is a dark-gray porphyry. The only megascopically recognizable phenocrysts are plagioclase, in crystals as much as 3 millimeters long, and pyroxene, in crystals about 1 millimeter long on an average but exceptionally 3 millimeters. In thin section the rock is seen to possess a seriate porphyritic texture with respect to the plagioclase, which, with the pyroxenes, occurs as phenocrysts in a micropoikilitic groundmass of quartz and orthoclase. Almost half the rock consists of plagioclase phenocrysts ranging from 3 millimeters down to about 0.2 millimeters, and a small amount of plagioclase of even smaller grain also occurs in the groundmass. The plagioclase shows combined carlsbad and albite twinning and is zoned very decidedly. The zoning is abnormal, inasmuch as the central zone is more sodic ($Ab_{62}An_{38}$ to $Ab_{55}An_{45}$) than the border zone ($Ab_{50}An_{50}$ to $Ab_{45}An_{55}$). The second mineral in abundance among the phenocrysts is hypersthene, with the normal pleochroism (X and Y reddish brown and Z greenish). The mineral occurs in phenocrysts ranging from 0.2 to 1 millimeter in length and in granules down to the limit of resolving power of a No. 7 objective. It is accompanied by normal augite. The augite is subordinate to the hypersthene among the phenocrysts but seems to be nearly equal to it among the granulitic pyroxenes. A small amount of biotite occurs, replacing augite and hypersthene along their borders and cracks. All these minerals are set in a microgranitic groundmass of plagioclase, orthoclase, and quartz. If the granulitic pyroxenes are regarded as a part of the groundmass, it constitutes about 40 per cent of the total rock; otherwise about 30 per cent. Magnetite and apatite are accessories.

The abnormal zoning of the plagioclase, the granulitic character of much of the pyroxene, and the occurrence of hypersthene in this rock combine to suggest that it is contaminated by assimilation of xenolithic material. The fact that the inner zones of the plagioclase consist of andesine, which is the common feldspar of the diorites and monzonites of the general region, together with the presence of the light-green, nonpleochroic augite, which is indistinguishable from that common to all these normal diorites and monzonites, suggests that this rock also was derived from the same magmatic source and that its aberrant features are due to local causes.

No xenoliths are recognizable in the rock, and if the abnormality is due to local assimilation the process appears to have been carried to completion. If it is assumed that the hypersthene is due to contamination of the magma, the appeal must be made to either limestone or quartzite as the xenolithic material, for the Oquirrh formation is almost free from shaly beds. It is difficult to see how addition of limestone to a magma saturated with diopside would act to transform this mineral into orthopyroxene, although it would readily account for the more calcic nature of the plagioclase border zones. Silica, on the other hand, as has been suggested by Bowen,[32] might react with an alumina-bearing diopside to yield anorthite and orthopyroxene, according to the reaction

$$SiO_2 + Al_2O_3 + CaMgSi_2O_6 = CaAl_2Si_2O_8 + MgSiO_3$$

The Fe necessary to produce hypersthene in association with the $MgSiO_2$ of this reaction may be assumed to have been derived from the hedenbergite molecule of the augite, according to some such parallel reaction as

$$SiO_2 + Al_2O_3 + CaFeSi_2O_6 = CaAl_2Si_2O_8 + FeSiO_3$$

The first reaction given above has been suggested by Bowen to be applicable only to basic magmas, and he differs with Evans's position[33] that such reactions are effective in producing orthopyroxenes in granitic magmas such as the charnockite series. However, with an intermediate magma, such as the monzonite of the Bingham district, containing about 58 per cent of SiO_2, such a reaction seems conceivable, especially in view of the prominence of augite and the sparseness of biotite among the mineral phases of the normal rock. Nevertheless such reactions are by no means the only ones that might have produced the minerals here found. Niggli[34] has supposed that when the water content of a magma is insufficient, rhombic pyroxene and potash feldspar are formed rather than biotite. Poverty of the magma in water may indeed be the

[32] Bowen, N. L., The behavior of inclusions in igneous magmas: Jour. Geology, vol. 30, pp. 549, 562, 1922.

[33] Evans, J. W., discussion of paper by C. E. Tilley, "The granite gneisses of Southern Eyre Peninsula (South Australia) and their associated amphibolites": Geol. Soc. London Quart. Jour., vol. 77, pt. 2, p. 133, 1921. Evans suggests the addition of argillaceous material to combine with magmatic silica.

[34] Niggli, Paul, Homogeneous equilibria in magmatic melts and their bearing on the processes of igneous rock formation: Faraday Soc. Trans., vol. 20, pt. 3, p. 434, 1925.

main factor in the persistence of pyroxene as a stable phase in the monzonite (or diorite) magmas of this area, but the hypothesis that it is the cause of the presence of orthopyroxenes has no support other than its mere possibility. This factor could not account for either reversal of the customary zoning of the plagioclase or the granulitic character of the pyroxenes, both of which appear to support the hypothesis of contamination by xenolithic material.

The specimen collected from the small plug downstream from the one whose rock has just been described has suffered so much weathering that its original mafic minerals are unrecognizable. However, its plagioclase exhibits zoning, from a more sodic interior to a more calcic exterior, in the same manner as in that rock, and the presumption is rather strong that it is a part of the same or a closely related body.

BUTTERFIELD CANYON

Distribution and structural relations. — Rocks classed by Boutwell as monzonite occur in considerable quantity on the north side of Butterfield Canyon, adjoining the Bingham Canyon area. Most of the bodies are sill-like, although the large mass just above the old Queen mine and the one in the angle between Blackjack Gulch and the main canyon have cross-cutting relations in part and are better classed as small stocks. The sills are only 20 to 40 feet thick as a maximum, and the stocks are likewise small bodies. There is every probability that all unite with the main mass of the monzonite at a rather moderate depth.

Lithology of principal type.—The commonest rock variety of these masses is a medium-gray fine-grained porphyry in which crystals of plagioclase, biotite, and pyroxene, rarely exceeding 1 millimeter in length, are the only megascopically recognizable phenocrysts.

In thin section phenocrysts of andesine (about $Ab_{60}An_{40}$), augite, and biotite are seen to occur in a granitic groundmass of orthoclase, quartz, and plagioclase. The phenocrysts are as much as 1 millimeter in length; the mineral grains of the groundmass rarely exceed about 0.4 millimeter in greatest dimension and average between 0.1 and 0.2 millimeter. The plagioclase occurs in fairly well-formed tablets only moderately zoned. It makes up about one-third of the entire rock. The pyroxene is a normal augite, light green, nonpleochroic, and with an extinction angle of 41°. It constitutes nearly a fifth of the rock. It is somewhat altered to hornblende in a very few places and to biotite somewhat more commonly but is chiefly quite fresh. The hornblende is pleochroic in green and brown, in small fibrous masses, and occurs only in small quantities. The biotite occurs not only around the edges of the augite as reaction rims but independently in the body of the rock. It forms about 5 per cent of the rock. Orthoclase is an abundant constituent, making up about 30 per cent of the rock. It is chiefly interstitial to the other minerals, but a few grains about 0.2 millimeter in greatest diameter are to be seen. Quartz makes up about 10 per cent of the rock, in irregular grains, few of which exceed 0.2 millimeter in diameter. Apatite, zircon, and magnetite are accessory, and a small amount of chlorite after augite and hornblende also occurs. The rock is a quartz monzonite porphyry.

Study of thin sections of rocks collected by Keith and Boutwell from the Bingham district, which included the stock near the Queen mine, shows that this rock is fairly representative of the monzonite of the Bingham district, although there is on the average probably a little more hornblende present in the rock of the Bingham district than in this. However, the Bingham rocks, like most of the monzonitic and dioritic rocks of the Stockton and Fairfield quadrangles, are characterized by the preponderance of augite among the dark constituents. Biotite and hornblende are locally more abundant than augite, and even where the biotite is subordinate to the augite it is more conspicuous in many places, both in the Bingham district and in the areas to the south covered by this report; none the less, the generalization just made is believed to hold.

Lithology of minor facies.—A small sill branching from the body north of the Queen mine is much more conspicuously porphyritic than the main body. It is a dark-gray rock with conspicuous phenocrysts of hornblende, biotite, and plagioclase in a dense groundmass. The hornblende blades are commonly 3 or 4 millimeters long and exceed this length in places. The other phenocrysts are smaller. The microscope shows phenocrysts of common green pleochroic hornblende, biotite, plagioclase (about $Ab_{70}An_{30}$), pyroxene (in small vestigial grains, largely altered to hornblende), and a small amount of quartz set in a groundmass of quartz, plagioclase, and subordinate orthoclase. The groundmass is very fine grained and makes up fully 60 per cent of the rock. This facies of the intrusive rock is to be classed as a quartz diorite porphyry. Despite the mineralogic differences between them, this rock is undoubtedly a part of the same body as the monzonite last described. Such local variations are, of course, to be expected in any intrusive rock.

SUMMARY OF STRUCTURAL RELATIONS

The dominant sill form of the smaller intrusive bodies and the evidence of thrusting action of one of the larger masses, together with the outlines of the

larger masses, suggest forcible intrusion as the mode of emplacement of these rocks. The writer sees in their relations no suggestion of "stoping."

RHYOLITES

SUBDIVISIONS

All the rhyolitic rocks of the Stockton and Fairfield quadrangles are intrusive. They occur in small stocks or necks and dikes, although one or two smaller bodies exhibit concordant relations and constitute sills. For purposes of description, these rocks are separated into three local formations—the Eagle Hill rhyolite, Shaggy Peak rhyolite, and Tickville rhyolite. The age relations of most of these rocks to the other intrusive bodies are not clear, as they are not in contact, but the Shaggy Peak rhyolite intrudes and hence is younger than the latite breccia of the Traverse Mountains. It is not in contact with any of the other intrusive rocks.

EAGLE HILL RHYOLITE

The Eagle Hill rhyolite was named Eagle Hill "porphyry" by Spurr,[35] from its exposures in the vicinity of Eagle Hill, just south of Mercur.

Distribution and structural relations.—The occurrences of this rock were interpreted by Spurr as sills and so appear on his maps. He calls attention, however, to the fact that "in places the boundary cuts across the bedding at a considerable angle, which sometimes is as much as 90°." The two large bodies of this rock near Mercur, one west of the Sacramento mine and the other on the top and south slopes of Eagle Hill, are both definitely crosscutting and transect over 800 feet of beds of the "Great Blue" limestone, as is clearly shown on the accompanying map. By no stretch of terminology can these bodies be referred to as "sheets." They are discordant throughout nearly every foot of their contacts. The rock mapped as Eagle Hill "porphyry" by Spurr and shown as narrow sills passing through the mines of Mercur and northward toward Rover Hill is shown by microscopic study to be either jasperoid, corresponding to the "Silver Ledge" of Spurr, or sandy limestone altered by contact metamorphism of the true Eagle Hill rhyolite or by hydrothermal solutions related to the ore mineralization. There are no igneous rocks exposed in the mines, according to Butler,[36] and although the mines are no longer accessible, exposures at and near the portals are still sufficient to show that the rocks which there resemble altered igneous material and were so interpreted by Spurr are actually altered sediments. No true igneous rock is exposed in Mercur Canyon north or east of the rhyolite body near the Sacramento mine.

However, small remnants of true sills composed of the Eagle Hill rhyolite are to be seen on the south side of Mercur Canyon near the mouth, about three-quarters of a mile somewhat south of east from the West Mercur town site, and in the NW. ¼ sec. 2, T. 6 S., R. 4 W. (unsurveyed). Neither of these exposures covers more than a few feet, however, and none can be said to be characteristic of the rock.

In Ophir Canyon a dike referred to the Eagle Hill rhyolite crops out from the bottom of the canyon nearly to the summit of the north wall at mineral monument No. 4. This dike ranges from 10 to 30 feet in thickness and cuts straight through its country rocks, without offset at either the Canyon fault or the Cliff fault. Its dip is essentially vertical. It is decidedly streaked, showing strong flow banding and sheeting parallel to the walls. This character was not observed in any of the other masses.

At its north end the dike appears to coalesce with an irregular mass of brecciated rhyolite and limestone which locally has the relations of a sill, although there is little doubt that it is chiefly crosscutting.

Northeast of mineral monument No. 4, near the top of the north wall of Ophir Canyon, are a few exposures of this rhyolite breccia containing a great number of limestone fragments. At first these exposures were interpreted merely as inclusions in the rhyolite, but careful study of many outcrops at this point and in Dry Canyon, where similar masses were observed, led to the discovery that all gradations occur between rhyolite containing sporadic angular fragments of limestone and limestone breccia containing isolated angular fragments of rhyolite. Many or even most of the limestone inclusions in the rhyolite are interpreted as xenoliths acquired during the original injection of the magma, but the rhyolite fragments in limestone imply either a renewal of intrusion which led to the brecciation of already consolidated rhyolite or postrhyolite faulting. The second suggestion is given weight by the fact that locally the rhyolite breccia follows the Cliff fault, but as the dike crosses the same fault a quarter of a mile to the south without being offset, it seems unlikely that important postrhyolite faulting has occurred here. Even if faulting has recurred at this point, the presence of a number of other breccia outcrops in Dry Canyon, so related as to be inexplicable by postrhyolite faulting, led the writer to the conclusion that most of the brecciation is due to renewal of intrusion.

A large mass of rhyolite breccia lies on the hill slope above the Dry Canyon portal of the Hidden Treasure mine. This body has obscure contacts, but may represent a sill, as little igneous rock occurs in

[35] Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 377, 1895.

[36] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 390, 1920.

constitutes a volcanic plug. The plug is about half a mile long and about a third of a mile wide, of roughly ovoid shape.

Lithology.—The Shaggy Peak rhyolite has two chief varieties. One variety consists of a light-gray rock carrying numerous rounded and fractured phenocrysts of very dark colored quartz ranging from 2 to 5 millimeters in length, with subordinate white or colorless feldspars of somewhat smaller size, in a groundmass that presents no directional features. This variety of rock occupies the central portion of the plug or at least makes up a large part of the plug. The other variety is more purplish gray, and contains far fewer and very much smaller phenocrysts. The dark quartz phenocrysts are chiefly less than 1 millimeter in length, and the feldspar crystals are of about the same size. A very few small flakes of biotite are also recognizable in hand specimens. These phenocrysts are set in a stony-textured groundmass which exhibits intense flow structure. Cross fractures due to tension during flow of the viscous mass are common, and fluidal lines marked by streaks of phenocrysts as well as slight variations in grain size are prominent. This variety of the rock forms the border of the mass, which accounts for the prominence of the flow structure.

Only one thin section of this rock was studied. This section, representing the fluidal border facies, exhibits strong sheeting on a microscopic scale. This sheeting is developed chiefly in the groundmass, and the phenocrysts of both quartz and sanidine are little broken. The quartz occurs in irregular aggregates of subhedral grains. Most of the aggregates are less than 1 millimeter in diameter. The sanidine crystals are chiefly oriented parallel to the streaking of the groundmass. They are more nearly euhedral than the quartz and form clear-cut prisms with small optic angle. They probably have a rather high soda content. No plagioclase phenocrysts occur in this slide. A few biotite crystals with frayed edges are present but offer no unusual or noteworthy features. Microphenocrysts of apatite and magnetite are not uncommon.

The groundmass is microcrystalline granular, with little or no glass, despite the small size of the phenocrysts, which would suggest very imperfect crystallization of the groundmass. Quartz and alkaline feldspar are the only recognizable minerals of the groundmass.

Classification.—The presence of quartz and sanidine as the sole salic phenocrysts and the negligible quantity of mafic constituents, together with the porphyritic development and very fine-grained groundmass, permit the classification of the rock only as a porphyritic rhyolite. Its distinction from the Eagle Hill rhyolite rests on its markedly different texture, the Eagle Hill rhyolite possessing few phenocrysts even in its coarser facies and nowhere exhibiting such marked flow structure as characterizes the border facies of the Shaggy Peak plug. The Shaggy Peak rock is also without plagioclase phenocrysts.

TICKVILLE RHYOLITE

Distribution and structural relations.—The rocks of five small bodies are here named Tickville rhyolite, because of the grouping of the masses near Tickville Gulch. All are intrusive, so far as could be discovered. Two small dikes of the Tickville rhyolite cut the Oquirrh formation in the SE. ¼ sec. 34, T. 4 S., R. 2 W., about half a mile west of Tickville Gulch; the other exposures of this rock are in section 26. The exposures near the center of section 26 are rather poor, but the rock appears to intrude the latite flows and the Oquirrh formation. A fifth exposure of the Tickville rhyolite forms the round white hill next east of the 6,355-foot hill on the north boundary of section 26. This mass appears to be a breccia plug which cuts through the Oquirrh formation.

Lithology.—The breccia plug just mentioned exhibits two principal rock varieties. One is a pale-gray to dull-white breccia, consisting of angular fragments of rhyolite in a rhyolitic groundmass. The other has a similar rhyolitic matrix but contains breccia fragments of rhyolite, quartzite, and some chert (or jasperoid) as much as 2 or 3 centimeters in diameter. Both varieties are highly altered, kaolinized, and silicified, with a porcellaneous appearance and decidedly conchoidal fracture. The only recognizable phenocrysts are quartz in crystals as much as 3 millimeters long and a few feldspars as much as 1 centimeter long.

The rock from the small plug near the center of section 26 is also highly altered. Its color ranges from pinkish and yellowish gray through light purplish gray to porcellaneous white. No brecciation was observed at this locality. Quartz phenocrysts as much as 3 millimeters long are common, and a few feldspar crystals as much as 6 millimeters long were recognized. No mafic minerals occur as phenocrysts. These rocks are also highly altered, and a small amount of pyrite has been developed.

The rocks of the dikes in section 34 are of a light cream color. Alteration has induced a chalky appearance. No noteworthy features beyond the occurrence of numerous quartz phenocrysts and sporadic minute quartzite inclusions were observed.

Alteration of all these rocks has been so intense that microscopic study reveals little more than megascopic study as to their original character. The silicified breccia contains a small percentage of quartz phenocrysts. These are considerably fractured but not notably resorbed and contain numerous inclusions of the groundmass of the rock. These phenocrysts are 1

or 2 millimeters in greatest length. All the feldspar phenocrysts have been altered beyond recognition of their original character. They are now represented by cavities of feldspar crystal shapes partly filled with spherulitic aggregates of a clay mineral. This mineral is probably dickite,[37] as it has oblique extinction and is optically positive, with birefringence of about 0.006 and with indices slightly higher than that of canada balsam. The groundmass has entirely lost its original character and is thoroughly opalized. No mafic minerals are to be seen. A little calcite and considerable sericite are present.

Little information is yielded by study of the sections representative of the dikes in section 34. Alteration has been so intense as to have masked almost completely the original character of the rock. However, a few broken phenocrysts of quartz and sanidine occur, as well as a very few of oligoclase. No mafic minerals are recognizable. The groundmass is thoroughly altered to isotropic material of lower index than balsam—presumably opal with perhaps a little allophane.

Classification.—Inasmuch as alteration of these rocks has been so intense, it is now impossible to ascribe accurate quantitative values to the original mineral constituents. The only statements which can be made with confidence are that quartz is the dominant phenocryst mineral and that sanidine is the next most plentiful. These facts suffice, however, for placing the rocks as rhyolites, in the qualitative classification of Rosenbusch. Although they resemble somewhat the more altered facies of the Eagle Hill rhyolite, the resemblance is not so close as to warrant the extension of that term to cover the rocks of these more easterly occurrences.

ANDESITE OR LATITE INTRUSIONS

The rocks discussed here would be classed as andesites from their microscopic characters. Their resemblances to the analyzed flow rocks, however, are exceedingly strong, and inasmuch as all the andesitic flow rocks analyzed carry notably more potassa than soda and hence are to be classed as latites, it is highly probable that chemical analyses would reveal the same relationships in these rocks. Thus they are tentatively called latite.

Distribution and structural relations.—Andesite or latite occurs as minor intrusions at two localities in the Fairfield quadrangle. The more conspicuous occurrence is the volcanic plug at Step Mountain, in the NE. ¼ sec. 16, T. 4 S., R. 2 W. This is a beautiful example of a volcanic neck, a cylindrical column of elliptical shape, about 1,000 feet long and somewhat less than 1,000 feet wide, standing as a prominent topographic feature above the volcanic breccias surrounding it. The topographic prominence of the neck is emphasized by a vertical bordering ring dike which can be traced entirely around the neck except for a short distance on the northwest flank where talus obscures the relations. (See pl. 10, *A*.) This dike has well-developed columnar jointing normal to its walls. This feature is seen in Plate 10, *B*, and it is doubtless in reference to the steplike profile of the columnar jointing that the name of the mountain was given. The center of the plug is of massive andesite or latite porphyry carrying many xenoliths, although the rock is not a typical agglomerate.

The other intrusion of andesite or latite porphyry is a dike in the northern part of sec. 4, T. 5 S., R. 2 W. This dike, which is about 50 feet in maximum width, trends northeastward and cuts through latite breccia for about a quarter of a mile; then, with a short offset, it cuts through the Oquirrh formation and bounds, in part, a small breccia plug. The dike dies out to the north near the line between Ts. 4 and 5 S., R. 2 W. This dike also has nearly horizontal columnar jointing similar to that of the ring dike at Step Mountain.

The small volcanic plug associated with this dike near its central part is only about 200 feet in diameter and appears to have nearly vertical walls. The andesite breccia composing it is highly altered and is stained red-brown throughout. It represents a minor volcanic vent.

Mention should perhaps be made of a much altered andesitic rock found along the east side of the rhyolite plug on the north flank of Bald Mountain, in the Stockton quadrangle. The specimen collected was too highly altered to permit any more definite statement than that the rock has an andesitic texture. The exposure is small, and nothing is shown of the relations of the rock to the rhyolite.

Lithology.—The dominant rock of the Step Mountain plug is a light-gray, very coarsely porphyritic biotite-hornblende andesite or latite. In hand specimens it closely resembles many of the latites of the flows but on the whole carries larger phenocrysts than most of the flow rocks. The plagioclase phenocrysts reach dimensions of 1.5 centimeters, hornblende 1 centimeter, and biotite 3 millimeters. In thin section the rock greatly resembles the latite flow rocks. The plagioclase phenocrysts are slightly more sodic than $Ab_{70}An_{30}$. Biotite and hornblende are much like those of the flow rocks, except that the hornblende is pleochroic in greens rather than browns and has a slightly larger extinction angle. Augite grains as much as 0.5 millimeter in diameter are abundant constituents of the rock. A few olivine crystals also occur. Several resorbed quartz crystals of rounded and embayed outline were seen, but it is difficult to

[37] Ross, C. S., and Kerr, P. F., Dickite, a kaolin mineral: Am. Mineralogist, vol. 15, pp. 34–39, 1930.

accept them as normal constituents of the rock, despite the occurrence of similar grains in many of the flows. It seems more likely that the quartz is xenolithic, a suggestion which receives some support from the considerable number of quartzite fragments of various sizes which the plug contains. A small amount of orthoclase appears in the groundmass of the porphyry. Apatite and magnetite are accessories. Analcite and other zeolites that are too fine grained for specific determination in thin section are present as alteration minerals. The texture of the rock is porphyritic, with a groundmass that ranges from pilotaxitic to microgranular.

A subordinate facies of the plug, with a darker and less coarsely porphyritic aspect than the main mass, appears near the borders. The only phenocrysts recognizable in hand specimens are hornblende, with a tendency to be arranged in rosettes. The microscope reveals a rock with green pleochroic hornblende, biotite, augite, and iddingsite pseudomorphs after olivine as the dominant dark minerals, set in a subvariolitic mass of plagioclase of composition slightly more sodic than $Ab_{70}An_{30}$. The hornblende also has a tendency toward radial arrangement, but the other mafic minerals are chiefly in irregular crystal aggregates. No unusual mineralogic features were noted in the rock, which is obviously merely a textural variant of the main mass.

The dike in sec. 4, T. 5 S., R. 2 W., is composed of light-gray quartz-bearing biotite-hornblende andesite or latite, with a bordering selvage a few inches to a few feet thick of dark-gray porphyry. The light-gray facies contains plagioclase phenocrysts of a composition close to $Ab_{70}An_{30}$, which reach 4 millimeters in length. Brown hornblende and biotite occur as phenocrysts. Augite is present in small amount, chiefly as groundmass microlites. A very few crystals of quartz occur as phenocrysts. Zircon, apatite, and magnetite are accessories. The texture is porphyritic, with a chiefly pilotaxitic groundmass that in places varies to hyalopilitic.

The mafic border facies of the dike carries only a slightly higher proportion of dark minerals than the light-gray central facies. No quartz phenocrysts are present. The only other differences between the two varieties are in the presence of a considerably greater number of augite microlites in the groundmass of the dark rock and in its larger percentage of glass. The texture of the dark facies is accordingly porphyritic with a hyalopilitic groundmass.

NEPHELITE BASALT

Distribution and structural relations.—Three sills of nephelite basalt occur near the west end of South Mountain, in the Stockton quadrangle, in secs. 17 and 18, T. 4 S., R. 5 W. The most easterly outcrop is in a saddle of the east-west ridge of South Mountain at about the 6,000-foot contour. The intrusion takes the form of a sill about 40 feet thick which can be traced for about half a mile. It is obscured by talus in both directions, so that how much farther it extends is not known, but inasmuch as it is rather thin at the extreme exposures the total length is presumably but little greater than the exposed length.

Two sills occur on the crest of the western summit of South Mountain but can be traced only a few hundred feet. Neither exceeds 15 feet in thickness. A fourth outcrop, too small to be shown on the accompanying map, occurs in a small gulch in the NE. ¼ sec. 13, T. 4 S., R. 6 W., on the north slope of South Mountain. This exposure probably represents a pipelike intrusion, for it can not be traced in any direction and occupies only a very small area.

Lithology.—The rock forming these sills is very dark greenish gray on fresh fracture, but weathers with rusty shades. It has a porphyritic texture, with phenocrysts of greasy-lustered olivine as much as 5 millimeters long and of biotite perhaps as much as 3 millimeters long in a fine-grained groundmass in which minute plates of biotite are the only visible grains.

The microscope reveals a porphyritic texture in which olivine forms the dominant phenocrysts, although it is in part inclosed poikilitically by still larger plates of light-colored biotite. The olivine cystals range from 0.3 to 5 millimeters in length and are subhedral, showing some resorption with development of a border phase of pyroxene and resultant partial obliteration of the crystal outlines. They constitute about 20 per cent of the entire rock.

Diopside, although the dominant mafic mineral, constituting about 40 per cent of the rock studied, occurs only in small crystals, ranging from about 0.05 to possibly 0.3 millimeter in length. These crystals are subhedral, most of them having the prism, side, and front pinacoids well developed, with terminal faces poorly developed or absent. Many of the crystals are poikilitically inclosed by biotite, and others exhibit slight resorption, with biotite as a magmatic reaction product. They are of pale-green hue, nonpleochroic, optically positive with notable dispersion, $\rho > v$, shown by the optic axis emergent on 100 and no dispersion shown by the axis emergent on the base. Extinction angles as great as 43° $Z \wedge c$ were measured. These properties do not indicate a notable content in alkalies.

The biotite is of late crystallization and incloses diopside and olivine, forming sporadic pseudophenocrysts about 2 millimeters in maximum size, although most of the biotite grains are less than 0.3 millimeter long and are interstitial. The mica exhibits variable pleochroism, most of it being abnormal, with absorp-

tion X>Y=Z, although some has normal absorption Y=Z>X. The biotite is of faint-yellow color, with darker hues around the borders of the crystals. Both the light and the dark portions of crystals show abnormal absorption, and in some individuals both show normal absorption. The mica makes up about 20 per cent of the rock. Mica having the abnormal pleochroism scheme of the variety first described has been reported by Ross [38] from a Montana alnoite, by Wagner [39] from South African kimberlite, and by Ross [40] from Arkansas kimberlite (peridotite). It seems to be not very rare in alkalic rocks.

The above-described mafic constituents are embedded in a matrix of anhedral nephelite. This mineral is colorless and exhibits parallel extinction with two cleavages, the better of which is parallel to the faster ray. In thicker portions of the slide the uniaxial negative character of the mineral is determinable. Its indexes are slightly higher than that of canada balsam and its birefringence not higher than 0.006. These properties suffice to determine the mineral as nepheline. It is interstitial to the mafic minerals, but areas in optical continuity and inclosing mafic minerals reach dimensions as great as 0.2 millimeter. The mineral makes up about 15 per cent of the rock.

Magnetite and apatite to the extent of about 2 per cent of the rock complete the list of primary minerals. No feldspar was observed in the slide examined.

The rock is remarkably fresh. The only alteration products observed were about 3 per cent of analcite and almost negligible quantities of a confused aggregate of cancrinite, hydronephelite, or some zeolite, such as thomsonite, with a fairly high birefringence. These minerals are probably derived solely from alteration of the nephelite by late magmatic or more likely hydrothermal reactions.

Classification.—As this rock is lacking in feldspar and carries nephelite as the only primary salic mineral, it is classed as a nephelite basalt, although the conspicuous biotite is an abnormal feature in nephelite basalt. The conspicuous biotite and the dark aspect give the rock a resemblance to the lamprophyre camptonite, but the absence of alkalic amphibole and plagioclase distinguish it.

LAMPROPHRYE (KERSANTITE)

Distribution and structural relations.—Lamprophyre dikes crop out in four places in Ophir Canyon. The exposures are all poor, owing to the rapid disintegration of the rock. The most southerly dike crops out on the northwest flank of Lion Hill, near the old Zella mine. The ore shoot in this mine is reported to have followed the dike rather closely. The dike is about 4 feet thick, dips vertically, and, though poorly exposed, can be followed with some interruptions for about a quarter of a mile northward from the Zella mine. A hundred yards or so to the south of the Lion Hill fault this dike is well exposed in two tunnels which have been driven along it. The dike can not be traced to the north of these prospects. However, nearly on the strike of this dike there is a small exposure of lamprophyre about 30 feet west of the portal of the new Ophir Hill adit. This dike is not continuous on the surface and can not be traced any appreciable distance, but a similar body of lamprophyre, now highly altered by hydrothermal solutions, was cut in the new Ophir Hill shaft at about 1,350 feet below the surface. Where cut in the shaft, this lamprophyre is of irregular shape but tends to conform roughly to the bedding.

On the north side of Ophir Creek there is a small exposure of lamprophyre on the east side of Hartmann Gulch, just below the headframe of the projected Ophir Central shaft. Here the rock forms a dike about 4 feet thick which strikes north and appears to have a nearly vertical dip. It is exposed for only a short distance and appears to be cut off by a fault of the Canyon fault system, but this is not certain. The rock probably crops out somewhere to the north in the east fork of Hartmann Gulch, as considerable float was found there, but diligent search failed to reveal the rock in place.

A fourth exposure of lamprophyre occurs on the Admiral Dewey claim, about half a mile north of the Ophir Central headframe. A prospect tunnel has been driven along this dike, which ranges from 1 to 4 feet in width. The dike strikes N. 40° E. and dips 70° W. It can be traced only a few hundred feet owing to talus and brush cover.

A lamprophyre is cut by the 7½ drift of the Ophir Hill mine, about 900 feet east of the 7½ No. 2 fissure. This is presumably a continuation of the dike that crops out on the Admiral Dewey claim. It is possible that this dike is the same as the one at the Ophir Central shaft. If it is, the dike is earlier than the Canyon fault and gives a measure of the horizontal displacement of that fault of about 800 feet, on the assumption that the dike is vertical at this point. However, in view of the apparent discontinuity of the dikes as known, it is not at all certain that the dike is cut off by the Canyon fault. They may be distinct intrusions of postfaulting age. If so there is no way of dating the lamprophyres within the igneous period; but if the lamprophyre is really cut off by the Canyon fault, it is older than the Eagle Hill rhyolite, which is younger than the fault. (See p. 58.)

[38] Ross, C. S., Nephelite-hauynite alnoite from Winnett, Mont.: Am. Jour. Sci., 5th ser., vol. 11, p. 219, 1924.

[39] Wagner, P. A., The diamond fields of South Africa, p. 58, 1914.

[40] Miser, H. D., and Ross, C. S., Diamond-bearing peridotite in Pike County, Ark.: U. S. Geol. Survey Bull. 735, pp. 315–316, 1923.

An exposure (too small to be shown on the accompanying map) of a rock strongly resembling these lamprophyres occurs on the crest of the ridge that rises north of the junction of the south fork of Ophir Creek with the main stream. The exposure is very small, and the rock could not be traced. No other lamprophyres were discovered during the survey of these quadrangles.

Lithology.—The lamprophyre is a dark-gray to greenish-gray rock of very fine grain. It readily weathers to a greenish or greenish-brown rock with spheroidal tendencies. One or two inclusions of quartzite were observed, but on the whole the rock is free from foreign material. The only mineral recognized in hand specimens is biotite, in very small plates, of which the largest hardly reach 1 millimeter in length.

In thin section the texture is panidiomorphic to hypidiomorphic. There is some tendency to porphyritic development of olivine (now represented by serpentine), some crystals of which reach 1 millimeter in length. The olivine shows considerable resorption, although enough of the original outlines remain to permit identification of the mineral. The reaction of the olivine and the residual magma during the consolidation process resulted in the formation of biotite borders around many grains. A great deal of biotite in well-formed plates occurs. This mineral has normal pleochroism. Very pale green augite is present in prisms, which, however, have poorly developed basal pinacoids. In many specimens the augite is considerably altered to uralitic hornblende, with faint pleochroism in greens. Plagioclase microlites and once-twinned plates occur with well-developed crystal faces. They are labradorite, with composition approximately $Ab_{45}An_{55}$. Apatite and magnetite are prominent minor constituents of the rock, and calcite is a conspicuous alteration product. One or two slides showed rather large crystals of quartz with reaction rims of biotite. These are probably xenoliths and are not uncommon in lamprophyres, despite the fact that many of these rocks are olivine bearing.[41]

The ferromagnesian minerals predominate over the feldspar. Among these minerals biotite appears to predominate, although in some specimens augite is more abundant. No hornblende except the uralite replacing the augite was seen. Olivine pseudomorphs occur in varying amounts, at most nearly 20 per cent of the rock, but in some slides very little olivine was seen.

The specimen collected from the new Ophir Hill mine shaft is highly altered. The biotite, olivine, and pyroxene of the original rock are recognizable by the ghosts of their crystal outlines and suffice to show, by their textural and quantitative relations, that the rock belongs to the lamprophyre suite. The rock is, however, reduced to a confused aggregate of bleached serpentine, carbonates, and an isotropic base of index n close to 1.55, probably halloysite.

Classification.—The texture of the rock and the predominance of biotite and plagioclase show that it should be classified as the lamprophyre kersantite.

[41] Rosenbusch, H., Elemente der Gesteinslehre, 4th ed., by A. Osann, pp. 329–330, Stuttgart, 1923.

GEOLOGIC RELATIONS OF THE IGNEOUS ROCKS

MUTUAL RELATIONS

As is evident from the detailed descriptions above, contacts among the several varieties of igneous rocks are few, and their mutual relations are accordingly not well known. This is especially true of all the igneous bodies west of the main divide of the Oquirrh Mountains, no two of which are in contact.

Little more detailed information is available with respect to the rocks in the northeastern part of the Fairfield quadrangle, but the general sequence is indicated—latite breccias, followed by latite flows, volcanic necks and dikes, and lastly monzonitic intrusions.

The wide diversity of rock varieties found at the base of the volcanic series affords little ground for any conclusions as to the relative order of eruption of the various rocks. The most that can be said is that of the volcanic rocks remaining in the area, latitic rocks form the overwhelming proportion; basalt, trachyte, nephelite basalt, and rhyolite obsidian all locally preceded them or were intercalated in the lower part of the series, and rhyolite and andesite or latite dikes followed them. Possibly the volcanic cycle was ended by basalt eruptions, but this is uncertain. It is perhaps noteworthy that here, as at many other localities in Utah, the most extensive fragmental deposits occur near the base of the series and the flows become increasingly abundant toward the top.[42]

As stated in the detailed descriptions, several latite dikes and two volcanic necks cut the extrusive rocks. This is naturally to be expected in any volcanic area and can hardly be considered evidence of any notable age difference. In fact, it is entirely probable that the Step Mountain volcanic neck was the source of at least a part of the extrusive rocks of the area. The Shaggy Peak rhyolite also may be only slightly younger than the rocks which it intrudes.

In Tickville Gulch (see p. 55) a small stock of dioritic rock is intrusive into a quartz latite flow. The intrusive rock is somewhat aberrant, but there is no

[42] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 89, 1920; Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 44–45, 1913. Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 54, 75, 1919.

evidence that it is of different age from the other dioritic or monzonitic rocks of the area. Accordingly it is tentatively held that the extrusive rocks as a whole antedate the intrusives, although the intervening time may have been very short. This conclusion is diametrically opposed to that reached by Emmons [43] and by Boutwell and Keith [44] in the Bingham district.

Although it would be easy to exaggerate evidence obtained from a single isolated exposure, such as the one in Tickville Gulch, especially in view of the somewhat aberrant composition of the intrusive stock, still the relations at this point are unequivocal, and there is no doubt that the dioritic rock has cut and metamorphosed the extrusive quartz latite. Therefore more weight is given to this one actual exposure than to the topographic relations which suggested to Emmons, Keith, and Boutwell that the extrusives were much younger than the intrusives. That the conclusion here set forth of a slightly greater age of the extrusives accords with the topographic relations of the two rocks is evident from the fact that it was advanced as a suggestion by Butler [45] merely from analogy with other neighboring localities and a study of the geologic maps. That all the rocks are comagmatic seems beyond doubt, because of the remarkable resemblances between the extrusives and intrusives and the rather constant composition of the intrusives throughout most of the Oquirrh Mountains. The rhyolites, lamprophyres, and nephelite basalts differ considerably in chemical composition from the monzonites and latites, but there is no reason to doubt that these are merely differentiation facies of the normal intermediate magma. The magmatic differentiation of the area is discussed on page 66.

SOURCE OF THE VOLCANIC ROCKS

The fine interbedding of tuffs and breccias and their diversity in dip due to postvolcanic disturbances leaves no clue as to the locations of their sources. It is safe to say there are no volcanic necks in the area of the main Oquirrh Mountains within these quadrangles which could have been a source for the material. However, Step Mountain, in sec. 16, T. 4 S., R. 2 W., is an old volcanic plug, and a second small plug occurs in sec. 4, T. 5 S., R. 2 W. It is very probable that still other necks existed in the area now covered by alluvium in Jordan, Cedar, and Utah Valleys, to the east of this area, for andesitic and latitic flows and breccias are very widespread in this part of Utah, being found in the Park City district, about 20 or 30 miles to the east,[46] and in the Tintic district, about the same distance to the south.[47] There is every probability that such necks communicate at depth with the magma chamber from which sprang the monzonitic and rhyolitic stocks now exposed by erosion.

The relative ages of the intrusive and extrusive rocks indicated by the evidence reviewed above is in line with the conditions found at Tintic [48] and in the San Francisco district.[49] Butler [50] has also given reasons for believing, contrary to the conclusions of Leith and Harder,[51] that in the Iron Springs district the intrusive rocks are the younger, the whole activity, however, being essentially continuous. Butler also describes similar relations in the Marysvale district,[52] in the Tushar Range, and points out that although Boutwell and Woolsey [53] note their belief that the extrusives of Park City are younger than the intrusives, still they postulate essential contemporaneity of the two.[54] In view of the additional information furnished by the present study, Butler's conclusion [55] that "the igneous rocks represent one long general epoch of igneous activity, during which both intrusion and extrusion occurred," seems strengthened. However, sight should not be lost of the fact that in the Deep Creek Range, only 90 miles west of the Oquirrh Mountains, a considerable period of erosion followed the intrusion of the plutonic rocks before the extrusives were erupted.[56]

DATE OF IGNEOUS ACTIVITY

From evidence obtainable within the Stockton and Fairfield quadrangles it can only be stated that the volcanic rocks of the area are much younger than the folding of the Paleozoic rocks and much older than the Lake Bonneville beds, of Pleistocene age. To fix the date more closely it is necessary to appeal to a parallelism in geologic history between this area and near-by areas.

As is pointed out on page 73, the most probable date of the folding of the Oquirrh Mountains is post-Cretaceous, probably very early Tertiary. The volcanism can accordingly be fixed as post-Cretaceous.

[43] Emmons, S. F., Geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pp. 24–25, 1905.

[44] Boutwell, J. M., and Keith, Arthur, idem, pp. 50, 55, 56.

[45] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 337, 1920.

[46] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 69–75, 1912.

[47] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 42–63, 1919.

[48] Idem, p. 75.

[49] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 50, 1913.

[50] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 571, 1920.

[51] Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, p. 46, 1908.

[52] Butler, B. S., op. cit. (Prof. Paper 111), p. 539.

[53] Boutwell, J. M., and Woolsey, L. H., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 93, 1912.

[54] Idem, p. 67.

[55] Butler, B. S., op. cit. (Prof. Paper 111), p. 99.

[56] Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation).

In the southern Wasatch Mountains near Santaquin,[57] at the south end of the East Tintic Mountains,[58] in the Canyon Range,[59] and in the northern part of the Wasatch Range [60] volcanism was later than Eocene conglomerate, and it is reasonable to suggest that the volcanism of the Oquirrh Mountains likewise occurred during late Eocene (post-Wasatch) or post-Eocene time.

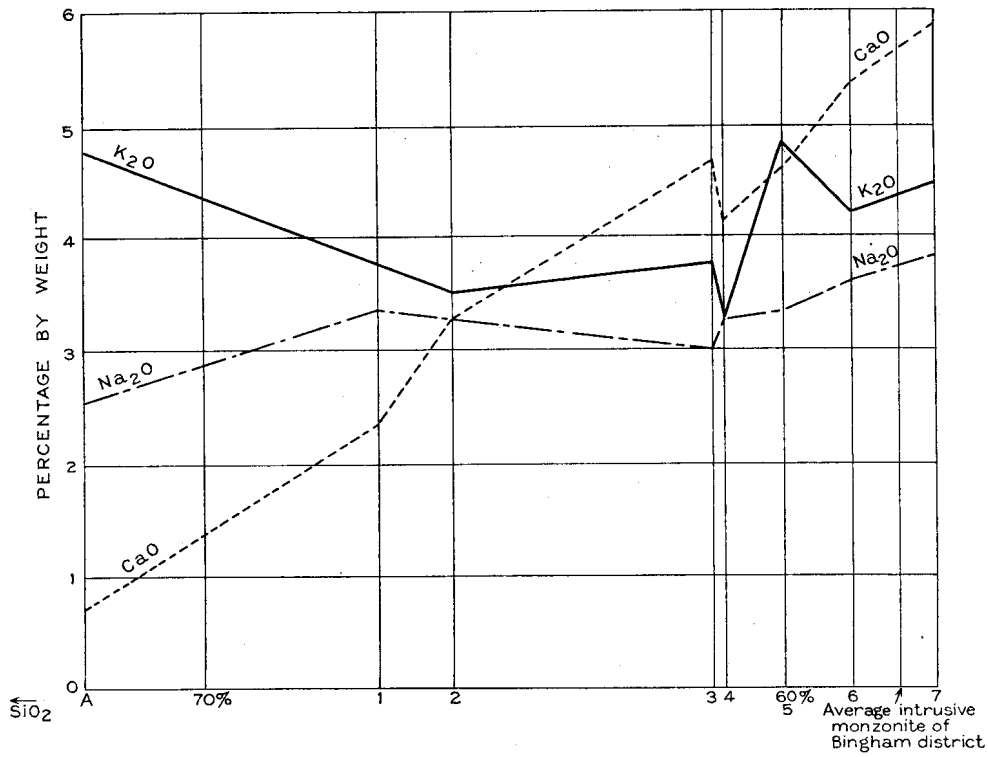


FIGURE 8.—Relations of weight percentages of CaO, Na_2O, and K_2O with variations in the silica content of the analyzed rocks from the Oquirrh Mountains. A, Rhyolite obsidian described on page 47; 1–7, rocks of which partial analyses are given below

There is evidence in the tilting of the volcanic rocks roughly parallel to the eastward tilt of the Oquirrh Mountain block (see p. 86) that the volcanism preceded the principal "Basin Range" fault movement of the Oquirrh block. The date of this movement is uncertain but probably not later than late Pliocene nor earlier than Oligocene. As the considerable erosion which must be conceded to have followed the volcanism in order to have exposed the intrusive rocks took place chiefly earlier than the faulting, a late Eocene or Oligocene date of the volcanism seems most reasonable.

PETROLOGIC RELATIONS OF THE IGNEOUS ROCKS

The close relationship between the chief varieties of extrusives is evident from their petrography. Although several of the type volcanic rocks described have the appearance of andesites, the fact that all of those analyzed have the alkali ratios characteristic of latites, whether they contain orthoclase or not, justifies the inference that all may belong to the latite and quartz latite groups. The consanguinity of these latitic lavas and the monzonites of Bingham is emphasized by the following regrouping of partial chemical analyses.

Partial analyses of predominant latitic volcanic rocks of the Fairfield quadrangle and monzonite of the Bingham district

	1	2	3	4	5	6	7
SiO_2	66. 90	65. 64	61. 09	60. 90	59. 86	58. 64	57. 16
CaO	2. 35	3. 26	4. 70	4. 16	4. 62	5. 37	5. 86
Na_2O	3. 34	3. 26	3. 00	3. 26	3. 31	3. 60	3. 82
K_2O	3. 75	3. 50	3. 77	3. 28	4. 84	4. 23	4. 49

1. Quartz latite from Tickville Spring, Fairfield quadrangle. J. G. Fairchild, analyst. (Contains individualized orthoclase in groundmass, none in phenocrysts.)
2. Quartz latite from northwest corner of sec. 2, T. 5 S., R. 2 W. Fairfield quadrangle. J. G. Fairchild, analyst. (Contains no recognizable orthoclase.)
3. Quartz-bearing latite from Oak Spring Canyon, Fairfield quadrangle. J. G. Fairchild, analyst. (Contains no recognizable orthoclase.)
4. Hornblende-biotite andesite (latite) from the Bingham district. Boutwell, J. M., and Keith, Arthur, Geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 130, 1905.
5. Hypersthene-augite latite from southwest corner of sec. 8, T. 4 S., R. 2 W., Fairfield quadrangle. J. G. Fairchild, analyst. (Contains individualized orthoclase in the groundmass.)
6. Monzonite, British tunnel, Bingham. E. T. Allen, analyst. Boutwell, J. M., and Keith, Arthur, op. cit., p. 178.
7. Monzonite, Tribune tunnel, Bingham. E. T. Allen, analyst. Idem.

[57] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains: Jour. Geology, vol. 21, p. 448, 1913.
[58] Tower, G. W., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 673, 1899.
[59] Loughlin, G. F., A reconnaissance in the Canyon Range, west-central Utah: U. S. Geol. Survey Prof. Paper 90, p. 51, 1914.
[60] Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 586–587, 1878.

Although the molecular ratios of potassa calculated from the percentages in these analyses do not equal those of soda, they are sufficient to demonstrate a monzonitic magma.

The two analyses of monzonite from the Bingham district may be considered representative of by far the most of the monzonitic rocks of the Stockton and Fairfield quadrangles. There are, however, many minor variations, as has been already pointed out in the petrographic description of the rocks. None of these variations, toward diorite, quartz diorite, granodiorite, or quartz monzonite, are sufficiently divergent from the average to imply more than very moderate differentiation. Comparison of these two partial analyses with the partial analyses of the latitic extrusive rocks reveals a decided relationship, shown especially well by the proportions of the alkalies. (See fig. 8.) Plotting the CaO, K_2O, and Na_2O as ordinates and the silica as abscissas reveals the interesting fact that the soda shows almost linear decrease with increase of silica. The average slope of the curve of soda is almost precisely that which would appear from the mere addition of silica to the monzonite magma. However, the lime decreases at a rate altogether disproportionate to the silica content, and the potassa remains very nearly constant or decreases at a much lower rate than the silica increases. This relationship is close to that which would be expected as a result of differentiation of a monzonitic magma by fractional crystallization, in accordance with the theory to which Bowen [61] has contributed so much weighty evidence. The more siliceous and less calcic character of the lavas as compared with the intrusive rocks is rational on the basis that the upper parts of the magma chamber, from which the early calcic minerals would be eliminated by sinking, would consistently furnish the material of volcanic eruptions.[62]

The rhyolite intrusions and obsidian flows may have been similarly derived from the originally monzonitic magma by the elimination through settling of the early formed crystals of calcic plagioclase and mafic minerals by crystal sinking; however, the lamprophyres are not satisfactorily explained on this basis—a fact that constitutes one of the most serious flaws in this theory of differentiation. Derivation of nephelite basalt from the same monzonitic magma by differentiation might seem incompatible with the sodic character of the nephelite rock, but the close association with the latites and monzonites favors this inference rather than the assumption of an independent magma.

[61] Bowen, N. L., The later stages of the evolution of the igneous rocks: Jour. Geology, vol. 23, No. 8, supplement, 1915; The reaction principle in petrogenesis: Jour. Geology, vol. 30, pp. 177–198, 1922; Origin of ultrabasic and related rocks: Am. Jour. Sci., 5th ser., vol. 14, pp. 89–108, 1927. Summarized in Bowen, N. L., The evolution of the igneous rocks, pp. 92–124, Princeton, N. J., 1928.

[62] Daly, R. A., Igneous rocks and their origin, p. 229, New York, 1914.

REGIONAL RELATIONS OF THE IGNEOUS ROCKS

Quite as noteworthy as the parallelism between the igneous history of Park City, Tintic, Marysvale, San Francisco, and possibly Iron Springs and that of the Stockton and Fairfield quadrangles is the striking similarity in composition of the igneous rocks of these localities. The igneous rocks of Gold Hill, Utah, are also very similar. This is clear from the following tables of partial analyses:

Partial analyses of intrusive rocks of western Utah and eastern Nevada

	1	2	3	4	5
SiO_2	58. 64	57. 16	59. 35	63. 46	59. 68
CaO	5. 37	5. 86	5. 03	4. 33	4. 63
Na_2O	3. 60	3. 82	3. 73	3. 66	3. 96
K_2O	4. 23	4. 49	3. 85	3. 49	2. 92

	6	7	8	9	10
SiO_2	61. 64	59. 76	62. 10	64. 41	66. 05
CaO	4. 65	3. 88	5. 31	3. 71	3. 93
Na_2O	2. 71	3. 01	5. 56	3. 60	3. 60
K_2O	3. 07	4. 40	3. 15	3. 46	4. 04

	11	12	13	14	15
SiO_2	64. 00	65. 29	63. 63	70. 67	62. 84
CaO	2. 95	4. 85	4. 46	1. 71	4. 72
Na_2O	3. 55	2. 10	1. 70	3. 95	2. 85
K_2O	5. 45	5. 18	5. 22	4. 85	4. 60

	16	17	18	19	20
SiO_2	69. 73	66. 64	65. 10	55. 25	59. 47
CaO	2. 20	3. 50	4. 66	7. 19	6. 24
Na_2O	3. 28	3. 41	3. 82	3. 48	2. 98
K_2O	3. 95	3. 72	2. 29	4. 11	1. 93

1. Monzonite, British tunnel, Bingham. E. T. Allen, analyst. Boutwell, J. M., and Keith, Arthur, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 178, 1905.

2. Monzonite, Tribune tunnel, Bingham. E. T. Allen, analyst. Idem.

3. Quartz diorite, ¾ mile northeast of Clayton Peak, Park City district, Utah. W. F. Hillebrand, analyst. Boutwell, J. M., and Woolsey, L. H., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 79, 1912.

4. Quartz diorite, east side of Brighton Gap, Park City district, Utah. W. F. Hillebrand, analyst. Idem.

5. Quartz diorite porphyry dike northwest of Daly West shaft, Park City district, Utah. W. F. Hillebrand, analyst. Idem, p. 84.

6. Quartz diorite porphyry, Valeo mine, Cottonwood Canyon, Park City district, Utah. W. F. Hillebrand, analyst. Idem.

7. Monzonite near Iron Dike mine, east of Silver City, Tintic mining district, Utah. H. N. Stokes, analyst. Tower, G. W., jr., and Smith, G. O., U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 647, 1898.

8. Quartz monzonite, Cactus tunnel, San Francisco district, Utah. George Steiger, analyst. Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 55, 1913.

9. Quartz monzonite, O. K. mine, Beaver Lake district, Utah. R. C. Wells, analyst. Idem, p. 57.

10. Quartz monzonite, Beaver Harrison dump, Beaver Lake district, Utah. R. C. Wells, analyst. Idem.
11. Quartz monzonite, Star district, Utah. R. C. Wells, analyst. Idem, p. 59.
12. Fresh andesite, east of Granite Mountains, Iron Springs district, Utah. R. D. Hall, analyst. Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, p. 49, 1908.
13. Weathered andesite, Desert Mound, Iron Springs district, Utah. R. D. Hall, analyst. Idem.
14. Granodiorite, Ibapah stock, Deep Creek Range, Utah. R. C. Wells, analyst. Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 96, 1920.
15. Quartz monzonite, Clifton district, Deep Creek Range, Utah. R. C. Wells, analyst. Idem.
16. Average post-Cambrian granite (Osann and Clarke). Daly, R. A., Igneous rocks and their origin, p. 19, New York, 1914.
17. Average quartz monzonite (Clarke). Idem, p. 25.
18. Average granodiorite (Osann and Clarke). Idem.
19. Average monzonite (Osann and Washington). Idem, p. 23.
20. Average quartz diorite (Osann and Washington). Idem, p. 26.

In spite of the range in silica content (from 70.67 to 57.16 per cent) shown by analyses 1 to 15, a range which is reflected in the varying quartz content of the rocks, it is clear that the proportions of CaO, Na_2O, and K_2O are all, except in the intrusives of the Iron Springs district, much closer to those of the average quartz monzonite than to those of any other of the "average rocks" given. The intrusive rocks of the Iron Springs district were called andesites by Leith and Harder, but it is clear that chemically they fall far outside the permissible limits of the andesites. They are assuredly latitic or even rhyolitic rather than andesitic. Butler[63] notes their strong resemblance to the other late intrusive rocks in Utah.

The widespread regional similarity of the effusive rocks is even more striking than that of the intrusive rocks. The volcanic rocks of all these districts are chiefly described as andesites and rhyolites, the former predominating. The andesitic rocks have been so named from their mineral composition. Wherever chemical analyses are available, however, it is seen that the so-called andesites are without exception so high in potassa that they are more properly classed as latites. Similarly, several so-called dacites resemble quartz latite much more closely chemically. This is apparent from the following table of the available chemical analyses of the "andesites," dacites, and latites of western Utah.

Partial analyses of andesitic and latitic rocks of western Utah

	1	2	3	4	5	6
SiO_2	66. 90	65. 64	61. 09	59. 86	54. 23	53. 75
CaO	2. 35	3. 26	4. 70	4. 62	6. 67	5. 95
Na_2O	3. 34	3. 26	3. 00	3. 31	2. 96	3. 18
K_2O	3. 75	3. 50	3. 77	4. 84	2. 80	4. 13

[63] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 97, 1920.

Partial analyses of andesitic and latitic rocks of western Utah—Continued

	7	8	9	10	11	12
SiO_2	57. 27	60. 17	68. 04	67. 93	64. 48	63. 04
CaO	6. 06	4. 69	2. 76	1. 42	1. 95	4. 13
Na_2O	2. 94	2. 96	4. 06	3. 54	4. 81	3. 43
K_2O	3. 23	4. 16	4. 27	3. 91	3. 39	3. 26

	13	14	15	16	17
SiO_2	57. 72	58. 04	61. 05	61. 52	57. 94
CaO	6. 40	6. 12	5. 40	5. 72	4. 91
Na_2O	4. 94	2. 26	1. 43	2. 31	1. 29
K_2O	4. 36	4. 08	5. 58	3. 02	8. 90

1. Quartz latite, Tickville Spring, Fairfield quadrangle. J. G. Fairchild, analyst.
2. Quartz latite, sec. 2, T. 5 S., R. 2 W., Fairfield quadrangle. J. G. Fairchild, analyst.
3. Quartz-bearing latite, Oak Spring Canyon, Fairfield quadrangle. J. G. Fairchild, analyst.
4. Hypersthene-augite latite, sec. 8, T. 4 S., R. 2 W., Fairfield quadrangle. J. G. Fairchild, analyst.
5. Andesite, Ontario tunnel, Park City district. W. F. Hillebrand, analyst. Boutwell, J. M., and Woolsey, L. H., U. S. Geol. Survey Prof. Paper 77, p. 74, 1912.
6. Augite latite, Volcano Ridge, Tintic district. George Steiger, analyst. Lindgren, Waldemar, and Loughlin, G. F., U. S. Geol. Survey Prof. Paper 107, p. 56, 1919.
7. Hornblende-augite latite, Tintic district. George Steiger, analyst. Idem, p. 63.
8. Latite, Tintic Mountain, Tintic district. H. N. Stokes, analyst. Idem, p. 69.
9. Quartz latite, Squaw Springs, San Francisco district. George Steiger, analyst. Butler, B. S., U. S. Geol. Survey Prof. Paper 80, p. 47, 1913.
10. Soda rhyolite, San Francisco district. George Steiger, analyst. Idem, p. 48.
11. Dacite, O. K. mine, San Francisco district. R. C. Wells, analyst. Idem, p. 48.
12. Dacite, San Francisco district. George Steiger, analyst. Idem, p. 46.
13. Latite or andesite, San Francisco. R. C. Wells, analyst. Idem, p. 47.
14. Andesite, Antelope Range, Iron Springs district. R. D. Hall, analyst. Leith, C. K., and Harder, E. C., U. S. Geol. Survey Bull. 338, p. 58, 1908.
15. Dacite, Sweet Hills, Iron Springs district. R. D. Hall, analyst. Idem.
16. Hypersthene-augite latite, Deep Creek. J. G. Fairchild, analyst. Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation).
17. Biotite-augite latite, Deep Creek. J. G. Fairchild, analyst. Idem.

Of these rocks, only the andesite of the Park City district and the dacites of the San Francisco district carry more soda than potassa, and even these are much higher in potassa than the average andesite and dacite as calculated by Daly. This widespread similarity in the chemistry of the igneous rocks of western Utah must reflect a regional magmatic character. However, it is impossible in the present state of our petrologic knowledge to be certain whether this is due to a widespread peculiarity of the original subcrustal magma or merely to a widespread similarity in the conditions before intrusion, such that the courses of differentiation of the several offshoots of the primary magma have been parallel. Much more information

about the regional geology and the igneous history will be needed before an attack on this problem can be hopefully made.

SUMMARY OF IGNEOUS HISTORY

The numerous points of uncertainty regarding the igneous geology of the Stockton and Fairfield quadrangles have been set forth above. However, despite the unsatisfactory status of information on these points, the following summary of the igneous history seems to be permitted by the known facts.

Probably in late Eocene or Oligocene time the maturely dissected surface of the northern part of the Fairfield quadrangle and probably also of the Stockton quadrangle was covered by volcanic materials. The nature of the earliest eruptions in the area is unknown. Among the oldest volcanic rocks remaining, however, are remnants of rhyolite obsidian flows and breccias containing fragments of latite, trachyte, and basalt, indicating a somewhat complex history of volcanism. This early phase, of fragmentary record, was followed by the formation of latitic pyroclastic rocks and latite and quartz latite flows. Some nephelite basalt dikes were also injected.

Contemporaneously with the superficial eruptions, magma was injected at depth in the form of stocks, sills, and possibly laccoliths, some of which extended up into the base of the pyroclastic series. It is probable that the latitic volcanic necks were fed by these or connected magma chambers. The volcanic rocks were then, in the closing stages of activity, penetrated by rhyolite dikes and plugs. The lamprophyres presumably were among the last products of the volcanism, which probably ended with minor basaltic effusions. It may be, however, that the basalts were much later and only remotely connected with the principal volcanic cycle.

STRUCTURE

GENERAL FEATURES

The chief structural features of the Stockton and Fairfield quadrangles include folds, faults, fissures, and the features related to igneous emplacement. The structural relations of the igneous rocks have been set forth in the preceding section; fissures to which ore deposition is known to be related will be treated in the section dealing with the ore bodies. It remains to describe the more general structural features, folding and faulting.

The southern Oquirrh Mountains and South Mountain, which together constitute about half of the Stockton and Fairfield quadrangles, consist for the most part of simple folds of large dimensions. Later volcanic deposits mask the sediments near the northeast corner of the area, and huge aprons of alluvium conceal the bedrock beneath Rush, Tooele, Cedar, and Salt Lake Valleys, but there is no reason to doubt that these portions of the area are likewise underlain by simply folded Paleozoic rocks, in attitudes analogous to those so well exposed in the uplands. The Oquirrh Mountains are bounded on the west by a series of faults in steplike arrangement. These faults sharply truncate the folds at varying angles, and to displacement along them is primarily due the existence of the range as a topographic feature. Other faults of great economic importance occur within the body of the range, but in general faulting, save for the mountain-front faults just mentioned, has been subordinate to folding throughout the area.

FOLDS

The strata composing the southern part of the Oquirrh Mountains are thrown into four large folds, two anticlines and two synclines, which are the dominating structural features of the Stockton and Fairfield quadrangles. These folds are subparallel, with northwest trends, thus making considerable angles with the crest and borders of the mountains. The axis of a transverse uplift crosses the range practically at a right angle to the trend of these major folds, and from this cross axis the folds plunge both north and south.

OPHIR ANTICLINE

The axis of the western anticline of the range, long known as the Ophir anticline, passes just west of the abandoned site of Sunshine, thence northwestward, about a mile west of Mercur, through Lion Hill (pl. 3, *B*), Ophir, and, farther northwest, through the Queen of the Hills mine in Dry Canyon and is interrupted just south of Soldier Creek by the zone of en échelon faults that limits the range on the west. A fold that is almost certainly the continuation of the Ophir anticline appears in South Mountain, across Rush Valley from this point.

In Ophir Canyon the Ophir anticline is cut by an eastward-trending zone of branching faults whose combined effect is a vertical displacement of the beds in excess of 2,000 feet. Just north of the fault, on the upthrown side, the oldest exposed rocks in the area are to be seen. A little farther north the anticline plunges steeply, so that the entire stratigraphic column up to and including the "Great Blue" limestone is traversed in following the axis northward before it is cut off by the mountain-front fault near Soldier Creek. In South Mountain the axis swings sharply to a more westerly trend than it has in the main range. The rocks composing South Mountain, with the exception of some altogether insignificant sills, belong entirely to the Oquirrh formation, indicating that the axis of

the fold has continued to plunge throughout its course north of Ophir Canyon.

To the south of Ophir Canyon the anticline plunges much more gently than it does to the north, but as the altitude also declines from Lion Hill southward, approximately the same geologic horizons are exposed well down the range. Silverado Canyon exposes the Humbug formation, and Mercur Canyon cuts slightly lower, penetrating the upper part of the Deseret limestone, but farther south no rocks are exposed older than the Humbug formation, which is to be seen in McFait and Mitchell Canyons. The "Great Blue" limestone is the surface formation over the entire anticline west of Manning Canyon and south of Soldier Creek except for the small areas of older beds exposed in the canyons just mentioned.

Throughout its exposed length the Ophir anticline is asymmetric, but whereas toward the south it is only slightly steeper on its eastern flank than on its western, the dips half a mile from the axis being about 25° to 40° and 10° to 25°, respectively, the asymmetry becomes more marked farther northwest. At the east end of South Mountain the northeast limb of the fold is vertical but the southwest limb dips only about 30°; 2 miles farther west the north limb is overturned and dips as much as 55° S., but the southern limb maintains its 30° west dip and north-south strike rather constantly.

POLE CANYON SYNCLINE

Bordering the Ophir anticline on the east is the Pole Canyon syncline, an open fold whose axis passes through Pole Canyon, trending parallel to that stream, and thence slightly west of north through the highest peak of the area, the 10,626-foot eminence about a mile north of Lewiston Peak. The axis trends north-northwestward from this peak and passes near the southwest corner of T. 4 S., R. 3 W., whence, curving slightly toward the west, it passes down Selkirk Canyon and is concealed beneath alluvium.

Throughout its course the west limb of this syncline is steeper than the east, the relations being complementary to those shown by the Ophir anticline and Long Ridge anticline. Like the Ophir anticline also, the syncline plunges both south and north from a point near the latitude of Ophir, more steeply toward the south and less steeply toward the north almost to Selkirk Canyon, where the axis pitches more steeply again. Despite this plunging and the great thickness of strata thereby exposed, the surface formation throughout the syncline is the Oquirrh formation

LONG RIDGE ANTICLINE

East of and subparallel to the Pole Canyon syncline is the Long Ridge anticline, so called because the axis of the fold almost coincides with the axis of Long Ridge. The axis of the fold trends northwestward from Long Ridge (south of which it is concealed by alluvium) through the head of Iron Canyon, passes thence near the old Mayflower mine and across the saddle between White Pine Flat and West Canyon, and leaves the area at a point near the common north corner of the Stockton and Fairfield quadrangles.

Like the Ophir anticline, the Long Ridge anticline is decidedly asymmetric, the southeast flank dipping much more gently than the northeast. This asymmetry is very marked near Middle Canyon, where the northeast flank stands practically vertical or is even overturned, whereas the southwest flank is characterized throughout by moderate dips.

From Long Ridge northward the axis of the fold plunges toward the north, somewhat gently near Long Ridge but more steeply beyond West Canyon. The result of the fold and the plunge of its axis is the exposure along it of the Humbug formation, "Great Blue" limestone, Manning Canyon shale, and Oquirrh formation in succession from southeast to northwest.

BINGHAM SYNCLINE

The corresponding downfold east of the Long Ridge anticline is the southward continuation of the Bingham syncline,[64] a structural feature named from the Bingham mining district, which it dominates. Owing to the volcanic cover of much of the northeastern part of the Fairfield quadrangle, it is difficult to trace the axis of this fold in detail; apparently, however, it passes near the mouth of Oak Spring Canyon and crosses the north edge of the quadrangle near the point where Butterfield Canyon leaves the area. The portion of this fold within the Fairfield quadrangle is not so markedly asymmetric as the Pole Canyon syncline. Both the limbs are very steep, in places even overturned, but the trough of the syncline appears to be very wide and open, as it is in the Bingham district, to the north. The northward pitch of the fold that characterizes it in the Bingham district is less steep in this area, and, indeed, it appears to pitch to the south near Oak Spring Canyon. In this respect the Bingham syncline resembles all the previously discussed folds of the quadrangles, for the pitch in all decreases toward a cross axis in an east-west line in about the latitude of Ophir. If the Bingham syncline can be said to have a cross axis, that feature is probably somewhat north of the common cross axis of the other folds. A small outlier of the Lake Mountains in sec. 25, T. 5 S., R. 2 W., is a part of the east limb of the fold. The axis of the fold seems almost level at this

[64] Boutwell, J. M., and others, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 56, 1905.

point. The northern part at least of the Lake Mountains southeast of this area seems to be a part of the fold. The Oquirrh formation is the only sedimentary rock exposed in the Bingham syncline within the Fairfield quadrangle.

MINOR FOLDS

Just east of the Bingham syncline near the edge of the Fairfield quadrangle there is a short segment of an anticline, whose west limb is formed by the steeply dipping east limb of the Bingham syncline. Exposures are very poor, and the diversely oriented joints of the quartzites of the Oquirrh formation, which is the only sedimentary rock exposed, render it almost impossible (in the absence of limestones) to determine accurately the attitude of the beds, so that the details of the fold are not certainly established. Such information as was obtained, however, indicates that the axis of the fold trends in a northwesterly direction, passing a short distance east of the center of sec. 25, T. 4 S., R. 2 W. Only about a mile of the length of the anticline is exposed within the area, but the northeastern limb dips north at an angle of about 60°, indicating that the axis of this fold, like those previously described, pitches northward. To the southeast the fold passes out of the quadrangles and constitutes most of the small part of the Traverse Mountains not included within the area.

Within the area of Rush Valley, near Morgan Warm Spring, a group of low rounded mounds rise above the alluvium. These mounds consist of the Oquirrh formation, dipping very steeply toward the west. A few small foothills of the Stansbury Range encroach upon the Stockton quadrangle. Their structural relations are of little moment, as they occupy so small a part of the area and belong to the main mass of the Stansbury Range rather than to the Oquirrh Mountains.

The attitude of the beds within the quadrangles, so far as it was determined, is shown on Plate 12, by the customary structure symbols. In the absence of recognizable "marker beds" within the Oquirrh formation, it is not profitable to attempt to show the structural relations by contours.

REGIONAL RELATIONS OF THE FOLDING

The northwesterly trend of the folds in the Stockton and Fairfield quadrangles is roughly parallel to that of the folds of the Tintic district[65] and Canyon Range,[66] to the south, and the folds in the southern part of the Wasatch Range.[67]

Several overthrust faults are present in the Wasatch Range, northeast of this area,[68] in the Cottonwood district. Overthrusts have also been reported by Loughlin[69] from the Mount Nebo region, at the south end of the range, and by Blackwelder[70] from the vicinity of Ogden, much farther north. All these thrusts have northerly trends and reveal movements of the overthrust block to the east relative to the underlying block.

About 90 miles to the west, in the Deep Creek Range, overthrusting in response to east-west compression has been recorded by Nolan.[71]

Butler[72] has called attention to the general north-south trend of the folds in western Utah, pointing out, however, that many folds strike in directions ranging from nearly northwest to considerably east of north. This subparallelism of the folds over a considerable region, combined with the notable thickness of the stratigraphic column involved in the deformation, leads to a postulate of regional pressure parallel to a roughly east-west direction as a proximate cause of the folding and thrust faulting. That this stress was exerted principally along a northeast-southwest line within the Stockton and Fairfield quadrangles seems probable from the general trend of the local folds in a direction normal to this. However, even within so small an area as that of the Stockton and Fairfield quadrangles this compressive force could not have been uniform, either in direction or in intensity. In fact, the more nearly east-west portions of the folds exhibit decidedly more asymmetry and even overturning than the more nearly north-south portions. On account of the large concealed areas beneath the valleys and the lack of sufficient detailed studies in the other near-by ranges it would be premature to attempt an "explanation" of this relation. If one is forthcoming it will be established only as a result of much more work than has yet been done in the region.

SUPPOSED EXTENSION OF THE UINTA AXIS THROUGH BINGHAM

Butler[73] in a discussion of the general structural relations in Utah pointed to the region between Bingham and Park City as the extension of the axis of the

[65] Lindgren, Waldemar, and Loughlin, G. F., op. cit., p. 21.

[66] Loughlin, G. F., A reconnaissance in the Canyon Range, west-central Utah: U. S. Geol. Survey Prof. Paper 90, pp. 53–58, 1914.

[67] Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 343–350, 1877.

[68] Hintze, F. F., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, p. 133, 1913. Loughlin, G. F., Reconnaissance in the Wasatch Mountains, Utah: Jour. Geology, vol. 21, pp. 439–443, 1913. Calkins, F. C., in Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 245–247, 1920.

[69] Loughlin, G. F., op. cit., p. 449.

[70] Blackwelder, Eliot, New light on the geology of the Wasatch Range: Geol. Soc. America Bull., vol. 21, pp. 517–542, 1910.

[71] Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: U. S. Geol. Survey report (in preparation).

[72] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 100–105, 1920.

[73] Butler, B. S., op. cit. (Prof. Paper 111), pp. 100–105.

Uinta Mountain uplift and hinted that intrusion may have been a factor in producing or at least in continuing such an uplift.

This suggestion has been accepted by Olmstead [74] and framed more specifically by Spurr,[75] Porter,[76] and Beeson.[77] Spurr believes that he can recognize the extension of the Uinta axis westward through Park City and Bingham, then with an offset to Tintic and west through the Deep Creek Range into Nevada. Porter,[78] however, believes that the Uinta uplift passes through the Bingham district, thence westward to the Stansbury Range. He attributes the localization of igneous activity and ore deposition principally to intersection of the traverse fractures of this system with the longitudinal fractures of the Wasatch and Oquirrh Ranges. He offers no explanation of the absence of igneous intrusions on the supposed extension of the axis through the Stansbury Range. In his earlier paper [79] he expressed the opinion that the widening of the Oquirrh Range in the latitude of Stockton and the Traverse Mountains is due to cross fracturing (and presumably to uplift) along the extended Uinta axis.

Beeson interprets the Uinta Mountains as due to an elongated laccolithic intrusion and believes that the intrusive mass and the uplift accompanying it extend westward through Park City, Big and Little Cottonwood Canyons, and the Bingham district. He states definitely [80] that a continuous "ore zone" accompanies this uplift and that the mineralization was not confined to isolated centers.

> The formation of this great zone of fissuring and mineralization [the "Bingham-Park City ore zone"] is believed to have been caused by the forces of mountain-making disturbances rather than the contraction stresses of the cooling magma, because the fissured zone is more or less restricted to an area about 2 miles wide and at least 40 miles long and parallel to the Uinta axis. The zone extends between and through the Bingham and Park City mining districts.[81]

Beeson suggests also that the localization of the zone of fissuring is due to its situation above the feeding dike of the supposed laccolith to which the roughly east-west anticlinal structure is attributed.

Without going deeply into the highly speculative question of the origin of the Uinta uplift it may be pointed out that no post-Cambrian igneous rock has ever been found in the Uinta Mountains themselves, although fully 30,000 feet of strata have been removed from the core by erosion and the base of the Cambrian where it unconformably overlies pre-Cambrian gneisses has been exposed. Accordingly if there is any intrusive mass present it is well down within the pre-Cambrian. Also there is evidence that the mountain mass is decidedly overthrust to the north,[82] which lends little support to a laccolithic theory of origin but seems to suggest tangential compression as a cause of the folding.

There is little doubt that the igneous intrusions in the Cottonwood and Park City districts have been effective factors in the deformation of those districts, and although they are crosscutting and can not be called laccolithic in shape they are assuredly either the causes or the accompaniments of a decided transverse upwarp which is doubtless correctly attributed to a westward extension of the Uinta folding. However, the geologic mapping of the Bingham district [83] and of the Stockton and Fairfield quadrangles shows definitely that far from being on an east-west or east-northeast uplift, the Bingham stock of monzonite is intruded in a deep downwarp of northwest trend. In fact, rough computations from outcrop data show that the base of the Ophir formation is probably not less than 18,000 feet below sea level near the center of the Bingham district, or fully 4 miles deeper than it is beneath Long Ridge, 10 miles to the south, and nearly 5 miles deeper than at Ophir. If there is an east-west uplift in the Oquirrh Mountains its axis must pass only slightly north of east, more probably almost due east, through the latitude of Ophir, thus being fully 10 miles south of the area of principal mineralization of Bingham. It is true that there is evidence of the existence of igneous material beneath the principal transverse upwarp near Ophir, and in the opinion of the writer the sharpness of the Ophir anticline at this place may be due in part to the intrusive force, as Butler first suggested.

The interpretation of the cross axis through Ophir as the extension of the Uinta fold seems to the writer only a little more plausible than the interpretation of the pre-Cambrian areas of Farmington and Antelope Island, 35 miles farther north, as the extension of this axis. On the evidence at hand, the question of a westward extension of the Uinta axis beyond the Wasatch Range seems an open one. In the opinion of the writer there is doubt whether it continues at all, though it is without question to be found in the Cottonwood district.

[74] Olmstead, S. G., Economic geology of the Ophir mining district, Utah: Econ. Geology, vol. 16, p. 437, 1921.
[75] Spurr, J. E., The ore magmas, vol. 2, pp. 475–485, New York, 1913.
[76] Porter, C. A., Intersecting fracture zones and mineral districts: Eng. and Min. Jour.-Press, vol. 118, pp. 650–651, 1924.
[77] Beeson, J. J., Mining districts and their relation to structural geology: Am. Inst. Min. and Met. Eng. Trans., vol. 75, pp. 768–792, 1927.
[78] Porter, C. A., discussion of paper by Beeson: Idem, pp. 793–796.
[79] Porter, C. A., op. cit. (1924), p. 650.
[80] Beeson, J. J., op. cit., p. 778.
[81] Idem, pp. 780–781.
[82] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, pp. 70–71, 1918; Oil possibilities in and around Baxter Basin, Wyo.: U. S. Geol. Survey Bull. 702, p. 38, 1920. Reeside, J. R., jr., Notes on the geology of Green River Valley between Green River, Wyo., and Green River, Utah: U. S. Geol. Survey Prof. Paper 132, fig. 5, p. 39, 1923. Irwin, J. S., Faulting in the Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 108–109, 1926.
[83] Boutwell, J. M., and others, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pl. 1, 1905

Porter's assumption that the wide part of the Oquirrh Mountains is associated with an extension of the Uinta axis is likewise not supported by field evidence. This wide place is purely an accident of topography due to late Tertiary faulting and has no relation to the early Tertiary folding and intrusion. The only east-west fold on this line is South Mountain, and it is sufficiently apparent that this is merely the curved extension of the Ophir anticline.

Spurr's generalization deals with units far beyond the scale of the present paper, but in so far as the disproof of an anticlinal location of the Bingham district intrusive throws doubt on its association with the Uinta anticline his generalization likewise must be questioned. As to any offset of the Uinta axis from Bingham to Tintic, there is no evidence of the presence of such an axis at Bingham nor of any faulting of sufficient horizontal displacement to account for such a lateral shift of 40 miles, and the areal geology renders such a speculation of doubtful validity.

In summarizing the regional structure it may be said that the Stockton-Fairfield area contains northward and northwestward trending folds reflecting compressive forces operating parallel to east-west or northeast-southwest directions, presumably associated in origin with similarly trending folds and overthrust faults of neighboring ranges. The supposed extension of the Uinta anticline to the west through Bingham and its superposition upon the folds of northward trend is definitely not a fact, and it remains questionable whether or not the nearly east-west cross axis through Ophir is a reflection of the north-south compression to which the Uinta fold most probably owes its origin. The association of the intrusive of the Bingham district with a very deep syncline is in marked contrast to the anticlinal location of the Cottonwood and Park City stocks, and there is therefore no consistent evidence to support the suggestion that the Uinta uplift is due mainly to igneous intrusion. The existence of igneous rocks from Mercur on the south through Ophir, Soldier Canyon, the Stockton district, and Bingham on the north renders an east-west trend of intrusions in the Oquirrh Range a matter of some doubt also.

DATE OF THE FOLDING

The information obtainable within these quadrangles suffices merely to place the date of the folding as post-Pennsylvanian and earlier than Lake Bonneville Pleistocene. However, the subparallelism of the folds and overthrusts over a much wider region justifies an assumption of approximate contemporaneity of folding throughout the region, and evidence of the date of deformation in neighboring areas is to this extent applicable to determining the date of the local folding. In the Tintic district[84] and the Wasatch Range[85] the Eocene conglomerates rest unconformably upon the eroded surfaces of these folds, fixing their age as greater than that of the Wasatch Eocene. Upper Cretaceous rocks are involved in the folding of the Wasatch Range, and according to Veatch[86] the major unconformity of the Cretaceous-Tertiary part of the section occurs between the Adaville (Upper Cretaceous) and the Evanston formations. The Evanston is pre-Wasatch in age and conformably overlain by the lower formations of the Wasatch group, though separated from the upper Wasatch by another though probably less pronounced unconformity. The presumption of a late Cretaceous to very early Tertiary date of the folding in the Wasatch Range seems well established, and accordingly this is the most likely date of the folding in the Oquirrh Mountains. However, the work of Veatch in southwestern Wyoming and of White,[87] Gale,[88] and Sears[89] in northwestern Colorado and the general summary of the whole problem of the deformation of the Rocky Mountain region of Idaho, Utah, and Wyoming given by Mansfield[90] show that compression and folding recurred during a considerable period in the general region of which this is a part and that a definite and precise date can not be established for the principal deformation of the Oquirrh Mountains. Probably most of the folding of this part of the Rocky Mountains occurred before Fort Union time, but that can not be proved locally.

Hintze,[91] Calkins,[92] and Beeson[93] have pointed out the significant fact that the overthrusts of the Cottonwood area are involved in the folding of the Uinta Mountains, showing at least a slight difference in age between the north-south folds and overthrust of the Wasatch Range and the east-west fold of the Uinta. In the opinion of the writer there is no evidence within the southern half of the Oquirrh Mountains that the later movement (the Uinta folding) found expression in this area. Thus the probabilities point to late Cretaceous or very early Eocene time for the Oquirrh folding.

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[84] Loughlin, G. F., op. cit. (Prof. Paper 107), pp. 103–104.

[85] Emmons, S. F., The Wasatch Range: U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 381–383, 1877. Wegemann, C. H., The Coalville coal field, Utah: U. S. Geol. Survey Bull. 581, pp. 161–184, 1915.

[86] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 76–87, 1907.

[87] White, C. A., in Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pt. 1, pp. 227–229, 1877.

[88] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 75–94, 1910.

[89] Sears, J. D., Geology and oil and gas prospects of part of Moffat County, Colo., and southern Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 751, pp. 291–293, 1924.

[90] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 379–384, 1927.

[91] Hintze, F. F., jr., op. cit., p. 128.

[92] Calkins, F. C., in Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 254.

[93] Beeson, J. J., op. cit., p. 779.

FAULTS

GENERAL FEATURES

The larger faults of the Stockton and Fairfield quadrangles fall into four principal groups. A group of major economic importance, because the faults displace the strata in which were found the Ophir Hill ore bodies, has its center in Ophir Canyon. Inasmuch as the faulted area extends to Silverado Canyon on the south, the faults will be collectively called the Ophir-Silverado fault group. The principal faults, both in magnitude and in economic importance, are those of Ophir Canyon. A second group of faults, possibly related to the Ophir-Silverado group but conveniently treated separately, is of less structural effect but of considerable economic interest. This group will be called the Dry Canyon fault group, as it centers in Dry Canyon near the Mono mine. Another principal group is the zone of en échelon faults which trend somewhat west of north along the west front of the mountain range and to whose displacements the existence of the range is due. This is a typical "Basin Range" fault system that has produced striking physiographic and structural effects. The fourth principal group is found in the mining area near Stockton and consists of numerous subparallel, westward-dipping normal faults. It is barely possible that this system is a part of the Basin Range system, but the faults are not topographically expressed and are, therefore, presumably of greater age; for this reason they will be considered separately. This group is of very great economic importance, the Stockton ores being genetically associated with it. Obscure bedding faults are numerous in this district also, but it is thought that they are principally connected with the folds, although some later movement has taken place along them.

Evidences of faulting are common at many other places throughout the quadrangles, but for lack of "marker beds" few of the faults could be mapped in any systematic way. Evidence is lacking, however, to show that any of them are of either economic or structural importance.

OPHIR-SILVERADO FAULT AREA

CANYON FAULT

Of the faults centering in Ophir Canyon the one of greatest magnitude and of principal economic interest is that locally called the Canyon fault. The Canyon fault is not a simple fracture but consists over most of its traceable outcrop of several faults, which coalesce and redivide at many places. The westernmost exposures of the Canyon fault are about a mile due north of the Ophir Canyon cemetery, where the great Lakes of Killarney fault of the Basin Range system transects the branches of the Canyon fault. These branches are both conspicuous because of the brecciated limestone associated with them. Their combined stratigraphic displacement is clearly in excess of 1,200 feet and probably is close to 1,500 feet, as the beds south of the fault are dropped relatively to those on the north, so that the base of the "Great Blue" limestone is almost opposite the base of the Madison limestone. The fault can be traced eastward, the branches rejoining, and can be followed up the gulch that descends the southwest flank of Dry Mountain. The displacement is here somewhat greater than at the more westerly locality, but probably does not exceed 2,000 feet. From this point eastward the fault, though of varying displacement, is increasingly conspicuous, both because of the contrast in the beds it has brought together and because of the more notable breccia associated with it.

The dip of the fault, which averages perhaps 60°–65° S., causes its outcrop to descend the southward-facing gulches of the tributaries to Ophir Canyon and to ascend the interstream spurs, so that its trace on the surface is considerably more sinuous than the actual fault surface.

The fault has several branches where it crops out in Bowman Gulch, and on the spur on which is situated the Ophir Hill Consolidated mill the fault movement is seen to have occurred on at least five distinct fractures. Of these fractures the northernmost one has by far the greatest displacement—about 1,400 feet. The total stratigraphic displacement of this fault zone south of the old Ophir Hill mine is more than 1,800 feet and is distributed on the major fault just mentioned and on four small faults south of it. These small faults, in order from north to south, have throws of approximately 160, 190, 160, and 30 feet, and it is probable that still another small fault exists beneath the alluvium of Ophir Creek. The large cumulative effect of all these faults is seen from the fact that beds somewhat above the base of the Lynch dolomite on the south side of the creek stand opposite to the Tintic quartzite on the north side.

The displacement of this fault zone is almost surely not all in a vertical sense, for the axis of the Ophir anticline is offset along it for fully 1,200 feet, possibly somewhat more, the south side having moved relatively eastward. If the small dike of lamprophyre below the abandoned shaft of the Ophir Coalition mine, on the north side of the canyon, is considered the offset extension of the dike just above the portal of the new tunnel of the Ophir Hill Consolidated Mining Co., on the south side of the canyon, the shift is 750 to 800 feet. Indeed, it is this lateral component of movement which is in a measure responsible for the variations in throw of the Canyon fault from place to place. Meas-

ured in a plane normal to the fault, the total throw is more than 1,800 feet at the old adit of the Ophir Hill mine, but opposite the new adit it is only a little over 1,000 feet, and still farther up the canyon, north of the grand stand at the baseball grounds, it is only about 600 feet. The first two localities are only about a quarter of a mile apart, and although it is believed that the absolute displacement must decrease somewhat in this distance, it seems most probable that this great difference in throw is due in large measure to the lateral component of the fault movement.

Practically all the subsidiary faults of this major zone trend about N. 70° E. and dip south at angles from 60° to nearly vertical. North of the Ophir Central shaft, however, a branch of more northerly trend splits off and passes up the spur east of Hartmann Gulch, at the crest of which its throw is about 100 feet measured by the displacement of the base of the Madison limestone. This branch fault could be traced little farther, as its displacement diminishes rapidly in this direction, and Madison limestone forms both walls, so that no distinctive horizons are available from which to determine the displacement.

East of the Ophir Central shaft the spur is cut by four other recognizable faults of the Canyon system, whose displacement is very difficult to determine exactly because of the variability in the lithology of the base of the Lynch dolomite, upon the dislocation of which the determination must depend. However, these faults, in order from north to south, including the more northward-trending branch just mentioned, appear to have throws of about 360, 90, 30, 130, and 380 feet. Still another fault of small throw, probably less than 30 feet, must exist beneath the alluvium of Ophir Creek at this place, for a distinct ledge of siliceous dolomite is identifiable on both sides of the creek, and a small fault must be inferred to explain its difference in altitude.

For a few hundred feet between the Ophir Coalition shaft and the baseball grounds, farther northeast, only two principal branches of the Canyon fault were clearly identified, but there are three just north of the baseball grounds. The two northerly ones are the larger, and their combined throws are close to 600 feet where they displace the base of the Madison limestone. A short distance farther northeast the fault traces descend into the valley alluvium and can no longer be followed. Doubtless, however, the fault becomes identified with the northeastward-trending Lion Hill fault, continuing at least 2 miles farther up Ophir Canyon.

Throughout most of their courses the several branches of the Canyon fault are marked by calcite-cemented breccia, but in places this is manganiferous calcite, and some pyritic quartz fillings occur in some of the branches above the Ophir Hill mill.

CLIFF FAULT

The Cliff fault is presumably a branch of the Canyon fault, for, although the possible junction of the two is concealed, the Cliff fault can be traced within about 200 feet of the Canyon fault, and the course is such that they are almost surely joined beneath a talus slope in the gulch southeast from Dry Mountain.

The general course of the Cliff fault on the spur west of the old Montana mine is N. 55° E., and its average dip is about 55° SE. On this spur the throw of the fault, as determined from the displacement of the hornfels at the base of the Bowman limestone, is about 140 feet, although the exposures are not as complete as could be wished, and the error in this measurement may be as much as 25 feet. The next exposure of the fault trace is west of the old Montana shaft in Bowman Gulch, where a breccia band and a zone of steep dips in the lower part of the Hartmann limestone afford evidence of the location. In the workings of the Ophir Hill mine the fault has been well exposed during the mining operations. Here it is composed of as many as five branches, which separate horses of the Ophir formation and strike between N. 15° E. and N. 45° E., averaging perhaps N. 25° E. The total throw of the faults composing the zone, as determined from measurements on the drain-tunnel level of the mine, is close to 270 feet.

Talus and brush make it difficult to trace the fault outcrop from the Montana shaft to the gulch just below the lowest tunnel of the Cliff mine. Here a small branch about 200 feet southeast of the main fault displaces the hornfels at the base of the Bowman limestone about 40 feet. The principal fault has a throw here of somewhat more than 300 feet. Slide rock conceals the fault for considerable distances up the hill from the lower tunnel of the Cliff mine, which is driven along the fault zone, but at the middle and upper tunnels there are good exposures. At both these places the fault is composed of several branches. It can be traced still higher up the hill and to a small saddle just west of the 9,450-foot hill south of Sharp Mountain, but soil and talus prevent further tracing, and it seems probable that the fault must die out within a short distance farther northeast.

The economic importance of the Cliff fault is very great, and in the discussion of the Ophir Hill and Cliff mines it will be necessary to consider the underground relations in some detail.

LION HILL FAULT

Another fault whose structural effect is equal to that of the Canyon fault is found in the north face of Lion Hill, south of Ophir Canyon. The most westerly exposure of this fault is a brecciated and calcite-cemented mass of limestone about 100 yards south of the railroad crossing and a mile east of the power house in Ophir

Canyon. A short distance west of this locality it is doubtless intersected by the Lakes of Killarney fault of the Basin Range system, though the crossing is concealed by talus. At the westernmost exposure the lower part of the "Great Blue" limestone south of the fault is brought opposite the middle of the Humbug formation on the north, a stratigraphic displacement of roughly 600 feet. Half a mile to the northeast the basal shale of the Deseret limestone north of the fault abuts against beds near the middle of the Humbug formation on the south, making the throw at this point about 900 to 1,000 feet. A small prospect hole dug on the fault furnishes an excellent exposure of it, from which it can be seen to be normal with a dip of 60°–68° S. It is marked by conspicuous breccias, cemented with quartz and to a less degree with calcite and carrying sufficient pyrite to produce a marked iron stain on weathering.

A short distance farther northeast along the fault there is a subordinate fault of flatter dip to the north of it. The trace of this fault joins the Lion Hill fault again half a mile farther northeast, including between it and the main fault a horse of Madison limestone. At the east end of this horse, due south of the Ophir schoolhouse, the fault has dropped the lower part of the Humbug formation against beds high in the Lynch dolomite. The exact throw there was not determined, but it is close to the aggregate thickness of the Madison and Deseret limestones, about 1,100 feet.

A little farther northeast a slice of Madison limestone similar to the horse just mentioned lies north of the fault and can be traced down the flank of Lion Hill into the bottom of Long Trail Gulch. The fault bounding this slice on the north is clearly seen on the spur followed by meridian 112° 15′ on the north slope of Lion Hill. Here the fault strikes N. 45° E. and dips about 62° SE., but the main Lion Hill fault, on the south side of the slice, strikes about N. 60° E. and dips somewhat more steeply. The included block of Madison limestone has been strongly rotated, striking N. 25° E. and dipping 38° SE.

The south fault passes south of the small 7,150-foot knoll east of Long Trail Gulch, through the saddle just west of the sharp curve in the wagon road from Ophir to the Three Metals tunnel, and down the northwestward-facing slope into the bottom of Ophir Canyon, which it reaches, as nearly as could be determined from the few exposures seen through the brush and talus cover, about at the northeast end of the baseball grounds. The north fault bounding the horse becomes less pronounced toward the northeast, passes north of the 7,150-foot knoll, and can be traced with great difficulty, because of brush and talus, for a short distance farther down the hill toward the canyon bottom. Here the alluvium of Ophir Creek conceals the relations of the faults of the Lion Hill group and those of the Canyon group, but as their trends are so nearly parallel it seems probable that the faults that can be traced up the hill east of the Jim Fisk mine and for a long distance farther up Ophir Canyon represent the union of the two groups. South of the Jim Fisk mine the combined throw of the faults seen and those which must exist beneath the alluvium is not far short of 2,000 feet.

East of the Jim Fisk mine the fault can be traced with some difficulty because of the thick brush cover and the large quantity of talus, but at least one branch passes across the nose of the hill northwest of the creek, about 400 feet above the creek bottom. The base of the Humbug formation on the north side of this branch is brought opposite to the top of that formation on the south side, so that the throw is about 650 feet. It seems necessary to infer a parallel fault in the creek bed in order to account for the much greater displacement of the beds south of the canyon with respect to those on the north side. From a point a few hundred feet farther northeast the fault sends off two small branches to the north. These branches are strongly marked by breccias but apparently are of slight throw. From this point the main fault curves more to the east. About 1,000 feet northeast of the junction of Ophir Creek and its principal southern tributary a fault of this system is clearly seen on a spur in the north wall of the canyon, where a wide breccia zone and marked drag in the limestone beds give evidence of its presence. From this point northeastward no breccia zone is seen, the fault trace dropping beneath the valley alluvium, but at two points somewhat farther upstream the limestones just north of the valley alluvium show abnormally steep dips toward the southeast, and it is evident from the offset of the Manning Canyon shale that the fault continues for some distance farther. The offset of the Manning Canyon shale due to the fault along the valley of Ophir Creek is about 1,000 feet, corresponding to a throw of practically an equal amount, as the dips on both sides of the fault approximate 45°.

MINOR FAULTS

Two minor faults parallel to the Canyon fault occur on the hillside southwest of the westernmost outcrop of the Ophir formation. One of these displaces the beds downward on the north rather than on the south, like the Canyon fault. These faults in conjunction with a small northward-trending break result in dropping a slice of the Madison limestone down into the Jefferson (?) dolomite outcrop, but the throw is slight. Similar small faults are common throughout the quadrangles, but most of them are too small to appear on maps of the scale of Plate 12.

A minor fault occurs in a tributary gulch that joins Silverado Canyon from the north at the 6,500-foot contour. This fault, which is cut off at its west end by a small northwestward-trending fault whose relations are very obscure, begins with a small displacement about a quarter of a mile from Silverado Creek and runs up the western spur of Chloride Point, passing over the shoulder of the spur at about the 7,950-foot contour. Thence it can be traced with great difficulty perhaps 1,500 feet farther on the northwest slope of Chloride Point, but its exact location is almost impossible to determine because of the very poor exposures, and the fault either dies out or is concealed east of a point north of the top of Chloride Point. The fault is normal, and its displacement is probably inconsiderable at both the west and east ends, but on the northwest spur of Chloride Point beds about 200 feet above the base of the "Great Blue" limestone on the north are dropped opposite beds possibly 300 feet below the top of the Humbug formation on the south, a movement of 500 feet or possibly somewhat less.

A similar normal fault on which the relative displacement has been down on the north crosses Silverado Canyon close to the 6,800-foot contour. Southwest of this point it passes up the west spur of Rover Hill and drops into the next gulch to the west, where it is cut off by one of the faults of the Basin Range system. It offsets the contact between the Humbug formation and "Great Blue" limestone nearly half a mile horizontally and must have a throw of close to 600 feet, slightly less than the total thickness of the Humbug formation. Northeastward the fault is traceable up the southwest slope of Chloride Point for about a quarter of a mile and then along the slope, parallel to Silverado Canyon, for about 1,000 feet. Its displacement diminishes rapidly throughout this course, and it finally becomes no longer traceable in the brush and talus a little west of south of Chloride Point. Its associated breccias are cemented by calcite and silica.

Faulting of complex nature is indicated in the foothills between Ophir and Silverado Canyons, especially in the valley tributary to Silverado Canyon near the 6,250-foot contour. Evidence for the faulting includes steeply dragged blocks of limestone along strongly brecciated zones, cemented with calcite and silica; its complexity is indicated by the divergent traces of the individual breccia zones and the evident and numerous local variations in strike and dip of the limestones adjoining them. However, the only formation represented in this locality is the thick "Great Blue" limestone, which is practically devoid of traceable marker beds, and no data were obtained that could be used to determine the amount of displacement on the faults. The crescent-shaped hill whose summit reaches an altitude of 6,800 feet in the divide between Ophir and Silverado Creeks is much cut by these faults, of which only a few of the most conspicuous were traced and are indicated on the accompanying map.

Evidences of a fault of uncertain but probably slight displacement are to be seen in the saddle between Sharp Mountain and the 8,757-foot hill about a mile southeast of it. Brush and slide rock prevent tracing of the fault, but its trend is such as to fall in line with the offset of the Manning Canyon shale across the next gulch to the east, and presumably that displacement is due to the same fault. Poor exposures near the Manning Canyon shale outcrop and the lack of other marker beds stratigraphically near it prevent accurate delineation of the fault and interpretation of its relations. It appears to be unimportant either structurally or economically.

AGE AND ORIGIN OF THE OPHIR-SILVERADO FAULTS

Three lines of evidence show that the faults of this group are of greater age than the principal movements of the Basin Range fault system.

1. There is no direct topographic expression of any of the faults of the Ophir-Silverado group, and the late-mature topography which extends from the south end of the range to Lion Hill and probably to Bald Mountain shows no displacement comparable to the movement of roughly 3,000 feet due to the Canyon and Lion Hill faults together. This topographic surface has been displaced by the movement of the Basin Range faults. (See pp. 81–86.)

2. The Canyon fault and its supposed branch, the Cliff fault, are both mineralized, and there is no evidence of any notable postmineral movement on them. Accordingly the faults of the Ophir Canyon group were in existence before the cessation of the deep-seated igneous activity which was the presumable source of the ore of the district. This activity was definitely earlier than the present topographic cycle, which was initiated by the Basin Range faulting.

3. Perhaps the most convincing evidence of the antiquity of the Ophir Canyon faults is furnished by the continuity of a conspicuous rhyolite dike which extends almost due south from mineral monument No. 4 and cuts without offset through the Cliff and Canyon faults. Obviously this dike, which is also of premineral age, is considerably older than the beginning of the present topographic cycle, and its continuity through the Canyon and Cliff faults fixes their age as definitely older than the end of the magmatic cycle. The possible offset of the dike that crops out above the new Ophir Hill adit may show that the faulting was later than some of the igneous activity.

Further evidence in support of this age assignment is presented in a discussion of the relation of meta-

morphism and mineralization to these faults in the Ophir Hill and Cliff mines (pp. 143, 150). In that place the directly contradictory opinion of Wichman [94] and Olmstead [95] that the faulting is postmineral is considered in detail.

The Canyon and Lion Hill faults can not be traced west of the points where they meet the Lakes of Killarney fault of the Basin Range system. This criterion of relative age, though given much weight by many geologists, is considered of doubtful significance by the writer, because transverse faults contemporaneous with the Basin Range system in other ranges have the same superficial relations. Also local stresses within a single block of faulted ground may well cause faults which are limited by earlier faults, although giving the superficial appearance of having been cut off by them. Fortunately the other criteria cited above are sufficient to settle the question.

Although it is believed to be established that the faults centering in Ophir Canyon are older than the mineralization, there is still no precise information as to their age. It seems probable, from the complete similarity of the portion of the Ophir anticline south of Lion Hill to the portion north of the Canyon fault, that the faulting was later than the main folding but perhaps contemporaneous with the later phases of the folding. Butler [96] considered that the faulting was due to the same forces that domed the strata and, accordingly, was of the same age as the development of the Ophir anticline. At any rate the conclusion is warranted that the Ophir-Silverado faults are not older than the principal folding (say latest Cretaceous) nor younger than the period of igneous intrusion. Probably their movement occurred during the igneous cycle, the early dikes being offset by the faults, the later ones passing through them without offsets. At present a more definite age assignment than to the period from late Cretaceous to middle Tertiary time seems unwarranted.

The origin of the faults is obscure, though perhaps the inference that they are due to differential forces acting in approximately vertical directions is warranted from their obvious close association with the anticlinal axis and their very steep dips. On the assumption that differential vertical forces were the proximate cause of the faulting, there are a number of possible sources of the forces. The faulting might be due to a marked local concentration of material and upward squeezing beneath the Ophir anticline during the folding and concomitant crustal shortening of the region, or it might be due to differential release of pressures subsequent to the folding. Another possibility is that the force of an igneous intrusion from below was concentrated on the portion of the Ophir anticline just north of the faults. There is evidence, in the localization of metamorphism along fissures north of the Canyon faults, that an igneous mass is not very far beneath the surface, but, of course, there is no proof that its emplacement involved the production of the faults now visible. From the data at hand it seems impossible to determine definitely the source of the forces involved, and further discussion of the point is hardly profitable.

[94] Wichman, F. M., op. cit., p. 562.
[95] Olmstead, S. G., op. cit., p. 447.
[96] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 376, 1920.

DRY CANYON FAULT AREA

MONO FAULT BLOCK

A group of faults of great economic importance but of most obscure origin and relationships is found in Dry Canyon, centering near the Mono mines. A pair of faults, locally called the Mark Antony and Garber faults, strike about N. 35°–40° W. and dip steeply northeast, passing through the saddle just east of mineral monument No. 5. Owing to poor exposures and the close association of the two faults they have been indicated as a single fault on Plate 11. Sporadic outcrops of breccia and the displacement of the Humbug formation, however, permit the tracing of the fault zone down the gulch toward the old Wandering Jew mine. The two distinct breaks farther northwest have probably joined in this vicinity, and the fault passes over the spur just northeast of the Wandering Jew incline and thence curves east and northeast to join a northeastward-trending fault locally called the Corbon No. 1 fault, near or at the portal of the lower Mono tunnel. The Corbon No. 1 fault strikes northeast near the portal and has a rather flat dip, about 30° W. Tracing this fault northeastward reveals a steepening of the dip to 60° or 65° and a more northerly swing of the strike. The fault passes up the gulch between the Mono boarding house and the Kearsarge mine but is concealed above the level of the road. At a point just west of the portal of the Brooklyn mine a fault, thought from surface geology to be the Corbon No. 1 fault, is exposed, but above the Brooklyn mine poor exposures prevent continuous tracing. It probably passes through the west side of the saddle between Sharp Mountain and Bald Mountain. Owing to the absence of distinctive marker beds in the "Great Blue" limestone it can not be traced farther. From underground mapping there appears to be some doubt that the Corbon No. 1 fault passes west of the Brooklyn mine, as projections of dips indicate a more easterly position. Surface exposures are too poor to settle this important question.

By reference to the map it can be seen that the Garber-Mark Antony fault and the Corbon No. 1 fault together outline a southward-pointing prowlike

mass, here called the Mono block because it contains the Mono mine. The Mono block appears to have dropped, relative to the adjacent rocks, with a throw of about 650 feet on the west side and perhaps 750 feet on the east, measured on the two sides opposite to the top of the Humbug formation within the block.

The keel or line of intersection of the faults bounding the block pitches N. 20°–30° W. at an angle of only about 25° for the first 300 feet from its outcrop, but projection of fault dips farther back from the prow of the block, in the latitude of the Mono boarding house, indicates a steepening of its pitch to 60° N. The grooving in the walls of the faults seems to indicate movements nearly normal to this keel, a direction in which important movements must be mechanically almost impossible. An attempt is made to show the relations of the block in Plate 11, but the block is cut too low to show the flat portion of the keel near the outcrop.

Within the Mono block there are many other faults (shown in pl. 29 but not in pl. 11), which are exposed in the Mono tunnels. The most prominent of these faults strike N. 45°–60° E. and dip 45°–80° NW. They appear, from their displacement of the Long Trail shale, to be normal, with downthrow on the northwest. Other less prominent faults within the block strike northwest and dip southwest at rather moderate angles. That they are normal seems indicated by the great distance which the lower Mono tunnel had to be extended to penetrate the Humbug formation, almost certainly because of duplication by these faults.

Any acceptable interpretation of these faults must assume simultaneous movement on both sides of the Mono block. Alternate faulting of first one side and then the other could conceivably result in the production of such a flat-keeled block as well as of fault grooving of the observed trends, but this interpretation must be rejected, because the basal shale of the Deseret limestone and the prominent reef of the Madison limestone pass unbroken and well exposed beneath the lower Mono tunnel, where at least one of the faults would of necessity cut these strata. Accordingly the bounding faults of the Mono block must be considered cognate, with simultaneous movement on them.

Three interpretations appear possible—(1) the block was thrust from the north between curving faults partaking of the nature of thrusts and transverse faults at the same time; (2) the block is the down-warped remnant of an overthrust; (3) the faults bounding the Mono block are normal, with the included block dropped between them. Neither of these interpretations seems wholly satisfactory, however.

The hypothesis that the Mono block arrived in its present position by thrusting from the north-northwest at a narrow angle to the keel, so that the Humbug and overlying formations overrode the Deseret limestone, was first suggested to the writer by H. G. Mitchell. According to this view, the Corbon and Mark Antony-Garber faults would be interpreted as rifts or transverse faults. The notable brecciation of the rhyolite and limestone on the dip slope forming the south wall of Dry Canyon opposite the Mono mine is considered by Mr. Mitchell as supporting this view, showing strong compressive movements in the direction of the keel of the Mono block. Inasmuch as the keel near the surface plunges northwestward at a slightly flatter angle than the dip of the beds, Mr. Mitchell's suggestion is geometrically satisfactory—that is, the relations observed could have been produced by such a movement.

There are, however, several objections to this view. One of these is the fact that the plunge of the keel probably steepens notably toward the north, so that it would be justifiable to expect, under this hypothesis, considerably more brecciation of the Mono block (by its compression between southward-converging faults) than is actually to be seen. The faults within the Mono block seem to have extended that block in the line of its axis rather than shortened it, as would be expected as a result of thrust faulting. Another objection is found in the trend of the fault groovings above mentioned, but as this trend does not agree with any likely direction of relative movement, perhaps it can be neglected.

Another point that appears to weaken the hypothesis of thrusting is seen in the widespread distribution of the brecciated rhyolite, which Mr. Mitchell considered fault breccia due to the overthrust. Such brecciated rhyolite is found not only on the dip slope of the south wall of Dry Canyon but over the divide in Ophir Canyon in many localities. It also occurs far underground in the Hidden Treasure mine and in the gulch east of the Kearsarge mine, all localities where thrust breccia could not be expected from the surface geology. Another objection to the hypothesis, though not an exceedingly strong one, is that no severe compressive forces are known to have been operating in a north-south direction in this part of the range and no thrust faults unless this should prove to be one.

The hypothesis that the Mono block represents a down-warped portion of an overthrust block seems inadequate, because of the situation of the Mono block near an anticlinal crest that has no other suggestion of depression and because of the steep dip of the keel of the block at the north end. The grooving of the fault walls would fit such an interpretation, however.

The interpretation that the faults are normal and the Mono block a dropped wedge appears to find its strongest support in the approximate parallelism of

the Corbon No. 1 fault, which bounds the block on the east and is conjugate with the Garber-Mark Antony fault on the west, and the system of three faults (or four, depending on the identification of the Corbon No. 1 fault) which run southwestward from the vicinity of the ridge line between Sharp Mountain and Bald Mountain. As is shown on Plate 12, these faults offset the Long Trail shale member and the base of the "Great Blue" limestone and throw the strata successively down on the west. They are all most simply interpreted as normal faults, and their parallelism with the Corbon No. 1 fault renders it highly probable that that fault too is normal. The extension of the block in the line of its axis by the numerous normal faults within it seems also decidedly to favor the hypothesis of normal faulting.

The interpretation of the faults as normal, however, though the one most favorably entertained by the writer in the field, meets some very serious objections. The first of these is the very flat pitch of the keel of the Mono block for the first 300 feet north of its outcrop, although the steeper plunge indicated farther north seems compatible with this interpretation. Furthermore, the pitch of the keel near the outcrop seems too flat to account by normal faulting for the elimination of almost the entire thickness of the Deseret limestone, 600 to 700 feet, within the short distance occupied by the "prow" of the block. The direction of grooving in the fault walls is contrary to that to be expected on this hypothesis.

Thus, no hypothesis considered by the writer seems to afford a completely satisfactory explanation of the observed facts, and although the hypothesis of normal faulting seems best to fit the geologic relations of the neighboring areas, the evidence in support of it is too inadequate to be offered with much confidence.

FAULTS ON SHARP MOUNTAIN

The determination of the faults that cut the southwest slope of Sharp Mountain is almost wholly dependent on recognition of the displacement of the Long Trail shale member of the "Great Blue" limestone. Exposures are very poor in this part of the area, and close study of the geologic map reveals that the Humbug formation as mapped is very much thicker here than in any other part of the quadrangles. This doubtless means that it is thickened by duplicating faults. This condition was, of course, recognized in the field, but diligent and protracted search failed to reveal other mappable faults. Innumerable breccia zones, which might and probably do represent fault outcrops, were observed, and their mapping was attempted, but with no success because of the lack of exposures and absence of marker beds in the formation. It can safely be concluded that other unmapped faults are present on the hillside northeast of the Hidden Treasure mine portal and that the abnormal thickness of the Humbug formation there is due to them.

Another fault of considerable displacement but too thoroughly concealed to be accurately mapped extends along the ridge south of Sharp Mountain. Its presence is indicated by the offset of the Long Trail shale member of the "Great Blue" limestone, but its position can not be determined within 200 or 300 feet, possibly even more. The limestone exposures show attitudes that completely preclude the presence of a roll in the bedding as the cause of the discordant relations.

DATE AND ORIGIN OF THE DRY CANYON FAULTS

There is less evidence bearing upon the date of the Dry Canyon faulting than upon that of the Ophir-Silverado group. The small rhyolite mass exposed at the mouth of the middle tunnel of the Mono mine is doubtless of identical age with the dike that cuts the Canyon and Cliff faults in Ophir Canyon, but it was impossible to ascertain whether or not this rhyolite mass is cut off by the Corbon No. 1 fault. The rhyolite is certainly not continuous across the fault, but it contains great quantities of limestone fragments, which may indicate that the mass was intruded along the fault rather than that the fault cuts it off. However, the rhyolite is cut off on the northwest in the tunnel by a fault which is roughly parallel to the Corbon No. 1 fault, and it seems reasonable to ascribe this fault to the same date as that of the Corbon No. 1 fault. If this inference is accepted, the Corbon No. 1 fault and presumably the entire Dry Canyon group of faults date from a time later than the rhyolite intrusion and are therefore younger than the principal Ophir Canyon faults. However, as the faults show some pyritization it is probably safe to assume that the faulting was earlier than the mineralization, and that the difference in age between the Dry Canyon and Ophir Canyon faults is probably not so great that the two groups can not be assigned to the same general period, which is roughly that of the igneous intrusion.

In view of the lack of decisive evidence as to the movements involved in the emplacement of the Mono fault block much uncertainty must attach to any analysis of the forces involved in the faulting. The general parallelism of the Corbon No. 1 fault and the three or four recognized faults on Sharp Mountain, which led to the tentative interpretation of the Corbon No. 1 fault as normal, naturally leads to a similarly tentative assignment of an identical cause for the production of the Corbon No. 1 and the Sharp Mountain faults. The curvature of the faults around the Mono block seems to indicate that here, too, as with the

Ophir Canyon faults, vertically acting differential forces caused the fracturing. It seems probable that uplifting forces acting on the periphery of the block are a less likely possibility as causes of the movement than depressive forces acting on the block itself, because the Sharp Mountain faults all drop toward the west, in the direction of the anticlinal axis, where, on the assumption of control by uplift during regional compression the reverse would be expected. Furthermore, the Mono block is negligibly small compared with the entire anticline, and there seems little likelihood of its having failed to respond to the uplift that produced the anticline. Thus the faults seem more accordant with a hypothesis of their origin by differential support from beneath during a period of relaxation following the folding than with one involving faults formed during compression. The possibility that the entire group may be due to forces arising from igneous intrusion below can not be dismissed, however, and it may be that intrusion was the real cause of the faulting. Of course, if the Mono block is really due to low-angle thrusting from the north, appeal must be made to quite different forces in seeking its origin.

BASIN RANGE FAULT SYSTEM

GENERAL FEATURES

Evidence of a zone of faults that separates the great mass of the Oquirrh Mountains from the alluvium-filled depression of Rush Valley is afforded by actual exposure of many clearly defined faults, by stratigraphic displacement, by transection of structure, and by topographic unconformity between the adjoining areas. Not all these evidences accompany each fault, but some of the faults show all four, and many are indicated by two or three of them.

The zone of faults has been traced from a point about a mile southeast of the mouth of Mercur Canyon to a point just north of Soldier Canyon, and has an average trend of about N. 20° W. There is reason to believe that the system continues along the entire west front of the range, although there is no unequivocal evidence to show it between Soldier Canyon and the north edge of the Stockton quadrangle.

The zone consists, within the Stockton and Fairfield quadrangles, of five principal faults, so far as available evidence indicates. In order from south to north these are (1) an unnamed fault of unknown displacement separating the mountain mass and the alluvium south of Mercur Canyon; (2) the West Mercur fault, almost continuously exposed from West Mercur to the Bates ranch at Ophir Creek; (3) the Lakes of Killarney fault, which is traceable from a point south of Silverado Canyon to a point about a mile south of Soldier Creek and is well defined just east of the Lakes of Killarney mine; (4) an unnamed fault which separates the block of "Great Blue" limestone just north of the mouth of Dry Canyon from the Rush Valley alluvium; (5) the Soldier Canyon fault, which can be traced for about a mile to the north and about 2 miles to the south from the mouth of Soldier Canyon.

FAULT SOUTH OF MERCUR CANYON

The southernmost fault of this zone is concealed beneath the alluvium in the S. ½ sec. 13, T. 6 S., R. 4 W. A prospect shaft about 60 feet deep and a few feet west of the contact between the alluvium and the "Great Blue" limestone penetrates, as shown by the material on the dump, a considerable thickness of black carbonaceous shale. Neither the Humbug nor the part of the "Great Blue" limestone exposed east of this shaft and dipping toward it contains any similar material, but such shale is present in the Long Trail shale member, higher in the "Great Blue." It is logical to infer that the shaft is sunk on the downthrown block west of the fault, thus penetrating these stratigraphically higher beds. The throw of the fault, on this interpretation of the relations, is about 100 to 200 feet. Additional support of this interpretation is seen in the sharp, steep scarp separating alluvium and limestone between the second gulch north of McFait Canyon and the gulch next south of the mouth of Mercur Canyon. Were these isolated occurrences, little weight would be attached to them as evidence of faulting, but similar features farther northwest are definitely associated with demonstrable faults, and the parallelism seems sufficient to warrant the conclusion. No traces of this supposed fault appear on its strike farther north, but the high tongue of alluvium which reaches an altitude of 6,000 feet just south of the mouth of Mercur Canyon conceals a considerable interval, and it may be that the fault curves westward to join the West Mercur fault or that it dies out in this interval.

WEST MERCUR FAULT

The West Mercur fault is a strongly marked fracture that passes through the old camp of West Mercur or West Dip and divides the rolling foothills on the northeast from the smooth alluvial slopes on the southwest. A low scarp with some interruptions marks the position of the fault and trends in a general course N. 30° W. from a point about half a mile southeast of West Mercur to the alluvial fill of Silverado Canyon, beyond which it is again traceable for a full mile to a point just north of Ophir Creek, at the Bates ranch. Between West Mercur and Ophir Creek the fault is exposed in prospect pits at several places as a marked breccia zone accompanied by dragged limestone beds. Where so exposed, the drag suggests that the fault is normal with the downthrow on the west. Accordingly

the scarps as exposed are interpreted as true fault scarps, only slightly eroded.

A particularly instructive exposure of the fault has been made in the inclined shaft of the Daisy (West Dip No. 1) mine, just south of the abandoned town site of West Mercur. The relations here are shown in Figure 9. A strongly slickensided mass of alluvium is separated by a black gouge from the limestone footwall of the fault. The drag in the ill-assorted fanglomerate of the hanging wall is not very clearly seen, because of the general absence of bedding, but it is perceptible, and the gouge and slickensides are well exposed. The fault dips about 60° W. here, but at a prospect pit a little less than a mile farther north it dips 49° W.

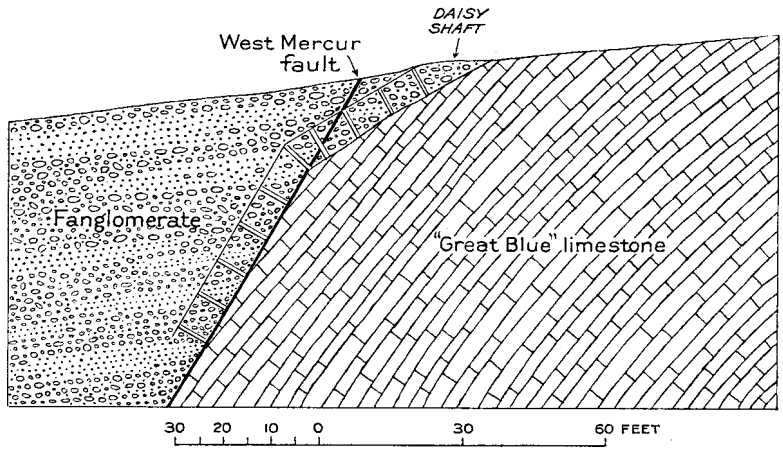

FIGURE 9.—Relations of West Mercur fault in inclined shaft of Daisy (West Dip No. 1) mine

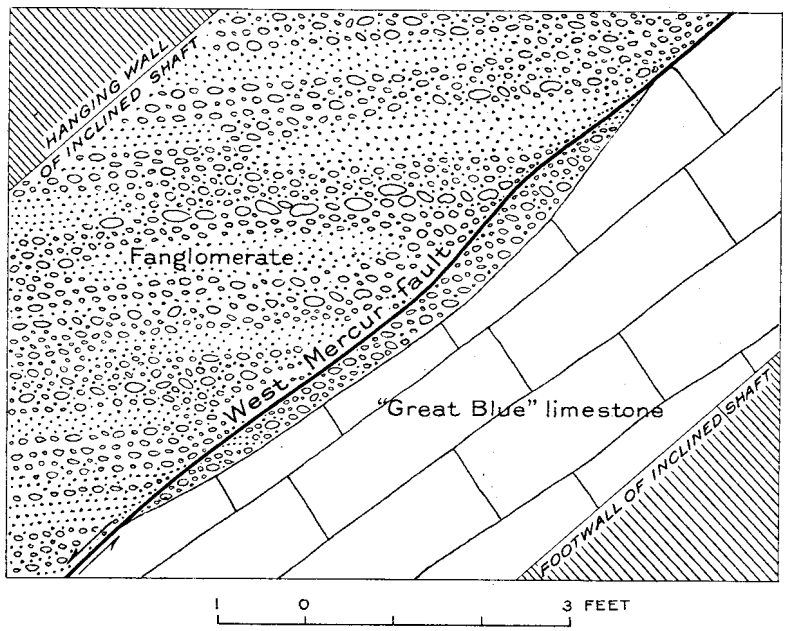

FIGURE 10.—Relations of West Mercur fault in inclined shaft of La Cigale mine

In the workings of the old La Cigale mine, about a mile farther north, similar relations are seen, as shown in Figure 10. The fault here dips about 40° W. and is exposed from the shaft collar, but the clearest exposure, illustrated by the sketch, is seen about 150 feet down the incline. Here the fault separates a footwall of "Great Blue" limestone from the hanging wall of alluvium. The alluvium is here finer textured than in the Daisy mine, and accordingly the drag of the fault is more clearly visible. Considerable gouge occurs on the fault and in two places is seen to cut through the alluvium, leaving undisturbed coarse gravel or fanglomerate in the footwall against finer-textured material in the hanging wall. This is clear evidence of rejuvenated movement on a fault which had had its scarp partly buried by alluvium.

The sharp break in the surface of the bedrock in this vicinity, as shown diagrammatically in Figure 11, is additional evidence that the lower contact of the alluvium is a buried fault scarp. The scarp is completely masked by alluvium, however, and is not exposed in the present topography for a few hundred feet in this vicinity.

The La Cigale and Daisy mines both found ore at depths of several hundred feet. The workings are no longer accessible. According to men familiar with these mines when they were in operation, the ore occurred in the fault, between limestone walls. The ore was very similar to that at the famous old camp of Mercur, about 3 miles east, and presumably was formed at the same time—a time fixed on grounds set forth below (pp. 84, 86) as almost surely pre-Miocene. The existence of the fault since early Tertiary time (though, of course, it does not follow that Basin Range faulting, as such, began at so early a date) is of interest in view of the recurrence of its activity in Recent time. A similar phenomenon, though not as well established, probably occurs in the Stockton mining district, about 10 miles to the north. (See p. 90.)

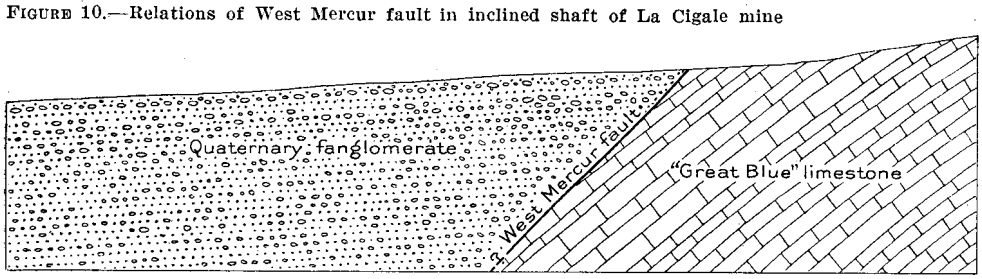

FIGURE 11.—Relations of West Mercur fault to the topography, alluvium, and bedrock near West Mercur

At the La Cigale mine the scarp does not project above the surface, but, on what is probably the same line of faulting, a scarp is to be seen in the alluvium just south of Silverado Creek, and a similar scarp with a displacement of about 40 feet occurs north of Ophir Creek just east of the road from Dry Canyon to the Bates ranch. (See pl. 9, *B*.) The fault was not seen north of Silverado Canyon except for a short distance just south of the Bates ranch, where it drops the Oquirrh formation on the west against the "Great Blue" limestone and Manning Canyon shale on the east. Although not well exposed, the dip here is probably about 55° W. Ample evidence for the existence of the fault, however, is seen in the sharp topographic break between alluvium and limestone and in the abnormally steep dips in the limestone along this line. The cappings of alluvium on the 5,950-foot hill just north of Silverado Canyon and on the larger 6,100-foot hill south of the power house in Ophir Canyon may owe their high position to uplift along this fault, but it is possible that they represent a higher stage of alluviation in a more arid period than the present.

LAKES OF KILLARNEY FAULT

Perhaps the most striking of the Basin Range faults in the Stockton quadrangle is the Lakes of Killarney fault, which crosses Ophir Creek just west of the 6,000-foot contour and trends about N. 40° W. It can be traced to the south by the strong topographic contrast on the two sides and by its own wide breccia zone. The breccia is exposed on the saddle east of the 6,500-foot hilltops on the divide between Ophir and Silverado Creeks and farther south on the hill between Silverado Creek and West Dip Gulch, on the south slope of which it is represented in a zone of vertical brecciated beds of the Long Trail shale member of the "Great Blue" limestone. It can not be traced farther and apparently dies out before reaching West Dip Gulch. The saddles through which the fault passes to the north are continued to the south, almost to the mouth of Mercur Canyon, but no faulting is associated with those south of West Dip Gulch, which are due to the presence of the easily eroded Long Trail shale member in the lower part of the "Great Blue" limestone. Dip measurements made by the three-point method on the breccia zone give 60° as the average dip of the fault south of Ophir Creek.

A breccia zone found in Silverado Canyon and apparently converging with the main fault just south of the stream bed is the only branch of this fault noted. As no recognizable marker beds other than the Long Trail shale member in the "Great Blue" limestone were discovered, the displacement of the major fault could not be accurately determined. However, the attitude of the beds cut by the fault and the thickness of "Great Blue" limestone exposed southwest of it seem to indicate that the fault begins at the south as a fracture of slight displacement which increases northward, reaching perhaps 1,000 feet on the divide between Ophir and Silverado Creeks and increasing yet more rapidly to the bottom of Ophir Canyon. A short distance north of Ophir Creek the Manning Canyon shale is dropped against the lower beds of the "Great Blue" limestone, a stratigraphic displacement of at least 3,000 feet. Perhaps half a mile north of the creek the fault is exposed as a slickensided surface, accompanied by considerable calcite-cemented breccia. Here its dip is 57° W. Across the next gulch to the north a small prospect pit exposes the fault, which has much limonite-stained gouge associated with it and locally strikes N. 55° W. and dips 80° SW. Some other prospect pits between this point and Dry Canyon expose the fault, though less satisfactorily. North of Dry Canyon the fault is easily traced by the breccia and steeply dipping dragged beds across the saddle east of the small 6,724-foot knoll. Here the displacement is indeterminate, though certainly not less than 2,000 feet and perhaps as much as 3,500 feet. The 3-point method here yielded a measured fault dip of 62° W. Followed north, the fault can be traced through the next saddle and then down the mountain side to the 6,250-foot contour, where it is masked by alluvium for about a quarter of a mile. About a mile north of Dry Canyon it emerges from the alluvium and crops out in a gulch as a steeply dipping breccia zone, along which the lower limestones of the "Great Blue" are dragged to a nearly vertical dip. The fault here strikes N. 20° W. and dips 65° SW. It crops out at intervals from this point north to the point where the mountain front swings sharply east, about a mile south of Soldier Creek, beyond which it is masked by alluvium. Its most northerly exposure reveals its dip as 60°. For most of the distance the fault divides the alluvial slopes from the limestone mountain, though it is itself covered at many places by alluvium.

UNNAMED FAULT NORTH OF DRY CANYON

Just west of the Lakes of Killarney fault, north of Dry Canyon, is a block of "Great Blue" limestone, which is cut off on the west by a fault of the Basin Range system. This fault is well exposed for nearly half a mile, and several prospect pits have been dug along it, in one of which the fault is seen to strike N. 5° W. and dip 54° W. This fault is cut by a poorly exposed fault trending a little north of east and dipping about 75° S. just south of the Dry Canyon road. To the movement along this eastward-trending fault is probably due the presence of the limestone hills north of Dry Creek, opposite the alluvial slopes south

of the creek. It is possible that the Basin Range fault is continued to the south of this eastward-trending fault, for in an inlier of bedrock exposed beneath the alluvium of Dry Canyon just south of the center of sec. 21, T. 5 S., R. 4 W., there is a marked breccia zone with associated dragged beds, indicating faulting of similar north-northwesterly trend and downthrow on the west. The fault shown in this small exposure is probably of slight displacement, however, inasmuch as the rock on both sides of it belongs to the Manning Canyon shale. It is probably merely sympathetic with the movements on the major faults just described.

SOLDIER CANYON FAULT

The Soldier Canyon fault begins obscurely about a mile north-northwest of Gisborn, where it separates the foothills from the main mass of Bald Mountain, and has been traced to a point a little over half a mile north of Soldier Creek, beyond which it could not be identified, owing to diminishing throw, poor exposures, and the fact that no recognized marker beds occur on opposite sides of it. The few exposures of this fault are limited to prospect pits. All indicate dips of about 50°–60° W. The exposures are particularly unsatisfactory, owing to talus and brush, and the displacement of even so good a marker bed as the Long Trail shale member is uncertain within perhaps 200 to 300 feet. This uncertainty is indicated on Plate 12 by the dotted contacts of this shale member on the east side of the fault.

OTHER FAULTS SUPPOSED TO BELONG TO THE BASIN RANGE SYSTEM

Faults parallel to the West Mercur fault occur east of that fault both north and south of Silverado Canyon, but as all are in the "Great Blue" limestone, where no good marker beds are present, it is impossible to ascertain their magnitude. The more prominent faults, judged by the widths of their breccia zones, are indicated on the map. A similar fault of unknown displacement runs about a quarter of a mile east of and parallel to the Lakes of Killarney fault for perhaps half a mile just north of Silverado Canyon.

It is probable that Basin Range faulting has occurred in the Stockton mining area, and some of the numerous faults exposed in that district may be of this system (see p. 90); but it is preferred to class as Basin Range faults only those which are directly reflected in the topography, and on this definition all the faults of the Stockton mining area, with possibly one exception, are excluded and will be discussed as a separate group.

The one exposed fault that is possibly to be assigned to the Basin Range system is visible for about a third of a mile north from Ben Harrison Gulch, opposite the Stockton Standard prospect. This fault dips about 40° W. as indicated by the silicified quartzite breccia marking it. This breccia forms a steep slope 50 to 100 feet high between two flattened slopes, the lower of which is capped by alluvium. That this fault belongs to the Basin Range system is by no means certain: it may be much older, as its position suggests that it is a northward continuation of the Muerbrook fault, the most conspicuous of the great number of mineralized normal faults of the Stockton district. Also its breccia is cemented with silica, presumably indicating no recent movement. But it is topographically expressed, and the sharp topographic break continues along the Muerbrook fault as far south as Southport Gulch, so that it is at least possible that some downthrow of the west block has occurred along this fault during the present erosion cycle. The amount of displacement of this topographically prominent fault could not be determined, but the Muerbrook fault, which occurs on its strike to the south and passes just east of the Black Diamond shaft, has a shift of fully 800 feet, the west side moving southward relative to the east. If the topographically prominent fault is identical with the Muerbrook fault, its present scarp must indicate recent rejuvenation of an old premineral (pre-Miocene) fault—a phenomenon already noted as having occurred on the West Mercur fault.

No other faults of the Basin Range system were observed in the area between Soldier Creek and Tooele. Nevertheless, full confidence is felt that the range front is here also controlled in the large by faulting, although in detail the wave cutting of Lake Bonneville is the cause of most of the distinctly alined transected spurs. The transection of the geologic structure by the range front which farther south and farther north[97] is due to demonstrable faults can here be justifiably referred to an identical origin.

GENERAL FEATURES OF THE BASIN RANGE FAULTS

Among the characteristic features of the Basin Range faults of the Stockton and Fairfield quadrangles are their steplike displacements, their en échelon tendency and consequent lack of persistence along the strike, their variable but prevailingly steep dips, and the possibility that some of the faults reflected in the present topography represent merely rejuvenation of much older faulting.

Distributive and en échelon faulting.—The displacement of the valley block with respect to the mountain block occurred on demonstrable distributive faults

[97] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 352, 1890. Atwood, W. W., The physiographic conditions of Butte, Mont., and Bingham Canyon, Utah, when the copper ores in these districts were enriched: Econ. Geology, vol. 11, p. 735, 1916.

from about the latitude of West Mercur nearly to Soldier Canyon. It is possible, though not certain, that the numerous subparallel, westward-dipping normal faults of the Stockton mining district, several miles farther north, have also participated in the Basin Range displacements, though the first movement along them probably dates back to pre-Miocene time. The largest of these, the Muerbrook fault, as mentioned above, falls in line with a topographically expressed fault and lends some support to the suggestion of step faulting furnished by the local more gradual mountain slope, such as has been described by Johnson.[98] Step faulting of units comparable to those south of Soldier Creek along Basin Range fronts has also been described by Gilbert,[99] Russell,[1] Louderback,[2] Reid,[3] Knopf,[4] and many others. There is every probability that many other faults bearing a steplike relation to those seen are concealed beneath the alluvium of Rush Valley.

En échelon arrangement of some of the Basin Range faults has not been so generally recognized, though it has been described by Louderback [5] and Knopf.[6]

The tendency toward en échelon arrangement of the Basin Range faults is evident on inspection. The fault zone trends N. 20° W., but the individual faults composing the zone trend N. 20°–50° W.

Length of faults.—The nonpersistence of the individual faults has been touched upon in the foregoing descriptions. Nothing is known of the extent of the West Mercur fault, as it passes beneath alluvium both to the north and south. The great Lakes of Killarney fault, bounding the mountain block for 4 miles, also passes out beneath the alluvium toward the north, but southward it dies out within less than 2 miles south of Ophir Creek. The Soldier Canyon fault can not exceed 3 miles in length. Nothing is known of the strike length of the faults farther north. It is probable that a fault occurs beneath the alluvium near the highway east of Bauer and Stockton, but no observations were possible to establish the inference.

The very different distances to which the southern spurs of the Oquirrh Mountains project into the lowland area of Rush Valley, which led Atwood [7] to interpret this portion of the range front as exhibiting an erosion topography, are clearly seen to be due to a combination of these factors of step faulting, en échelon faulting, and linear discontinuity of the individual faults. The topography is as clearly a fault product as that of the range front north of Tooele, which he interpreted in that way.

This somewhat complex pattern of the Basin Range faults is in contrast to the common diagrammatic representation of those features, but is by no means unusual in the Great Basin. Louderback,[8] Reid,[9] Lawson,[10] and Knopf [11] have described similar features. Gilbert concluded, after a thorough study of the Wasatch Range, that whether or not the Wasatch is typical of Basin Ranges in its contour, great simplicity of basal outline is evidently not an essential characteristic of faulted range fronts.[12] The present study supports this conclusion.

Dips of faults.—An additional point of interest in connection with the frontal faulting of the Oquirrh Mountains is the prevailingly steep dip of the fault planes. Fourteen measurements of dip were made, either on bedrock fault surfaces or by the 3-point method, in places where the topographic relief of the country traversed by the faults was sufficient. The measurements range from 40° to 64° and average 57°. The West Mercur fault changes in dip from 40° to 60° within about a mile, showing that the faults, as would be expected, are surfaces warped in dip as well as in azimuth. The other faults show comparable variations. The relation of the dip of the faults to the angle of slope of the fault scarps is discussed elsewhere,[13] the conclusion being reached that the angles of slope of the fault scarps are not indicative of the actual dips of the faults, as has been maintained by Davis and Gilbert, but that the scarps slope at lower angles than the faults.

AGE OF FAULTING

Early movement.—That there have been repeated movements, all later than the folding, on the West Mercur fault seems well established, and the same may be true of the Muerbrook fault. However, the dates of the repeated movements of the West Mercur fault can not be fixed with precision from the evidence at hand.

[98] Johnson, D. W., Block mountains in New Mexico: Am. Geologist, vol. 31, pp. 135–139, 1903.

[99] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 348, 1890.

[1] Russell, I. C., A geological reconnaissance in southern Oregon: U. S. Geol. Survey Fourth Ann. Rept., pp. 431–461, 1883.

[2] Louderback, G. D., Basin Range structure of the Humboldt region, Nevada: Geol. Soc. America Bull., vol. 15, pp. 307–308, 1904; Morphologic features of the Basin Range displacements in the Great Basin: California Univ. Dept. Geology Bull., vol. 16, pp. 17–25, 1926.

[3] Reid, J. A., The geomorphogeny of the Sierra Nevada northeast of Lake Tahoe: California Univ. Dept. Geology Bull., vol. 6, pp. 112–136, 1911.

[4] Knopf, Adolph, Geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, pp. 78–89, 1918.

[5] Louderback, G. D., op. cit. (1926), p. 29.

[6] Knopf, Adolph, op. cit., p. 89.

[7] Atwood, W. W., The physiographic conditions of Butte, Mont., and Bingham Canyon, Utah, when the copper ores in these districts were enriched: Econ. Geology, vol. 11, p. 735, 1916.

[8] Louderback, G. D., op. cit. (1926), p. 25.

[9] Reid, J. A., op. cit.

[10] Lawson, A. C., Recent fault scarps at Genoa, Nev.: Seismol. Soc. America Bull., vol. 2, pp. 193–200, 1912.

[11] Knopf, Adolph, op. cit., pp. 78–89.

[12] Gilbert, G. K., Studies of Basin Range structure: U. S. Geol. Survey Prof. Paper 153, p. 22, 1928.

[13] Gilluly, James, Basin Range faulting along the Oquirrh Range, Utah: Geol. Soc. America Bull., vol. 39, pp. 1103–1130, 1928.

Premineral movement along the West Mercur fault can not be proved in the mine shafts that remain accessible, but inasmuch as ore was reported to have occurred in the fault and was mined at points distributed along the strike for more than 2 miles, it seems very probable that the ore was originally deposited in the fault and not merely dragged in and that the first movement on the fault therefore antedated the mineralization. The ores of the Daisy and La Cigale mines greatly resembled those of the Mercur district, only about 3 miles to the east, and the presumption that they were deposited at approximately the same time is justifiable. If it is assumed, then, that the first movement on the West Mercur fault antedated the mineralization and that the mineralization at West Mercur was contemporaneous with that at Mercur, it remains to establish the age of the mineralization at Mercur. This question is likewise one that can not be answered directly from evidence within the area.

The mineralization of the several districts of the Oquirrh Mountains was closely associated with the igneous intrusions and did not occur in parts of the range where igneous rocks are absent. Without regard to the moot point whether or not the igneous intrusions furnished the source of the ore, it is a reasonable inference that the ores and the igneous activity are somehow genetically related, and accordingly the date of the mineralization may be presumed to be almost the same as that of the igneous activity. On grounds discussed previously, this date is fixed as falling sometime in the early Tertiary. Accordingly it seems probable that the West Mercur fault dates from early Tertiary time.

Basin Range movement.—There is no direct means available of determining the amount of movement that occurred on the West Mercur fault, either at the time of its inception or later. But evidence of repeated movement along it and the presence of the fault scarp in the alluvium at the Bates ranch testify to its activity until Recent time. Presumably the period of principal movement along it was the same as that of the principal movement on the other Basin Range faults—that is, the movement which is expressed in the present topographic relief of the country.

The local geology here again furnishes no definite information as to the date of this Basin Range movement. The latest consolidated rocks cut by the faults are Carboniferous and obviously offer no clue as to the date, but inasmuch as the folds are also transected and evidence has been advanced above to show that the folding was probably early Tertiary, there is no doubt that the Basin Range faulting is of later date than that. For more definite information recourse must be had to analysis of the topography of the area.

The topography of the southern and eastern slopes of the Oquirrh Mountains is in the stage of pronounced early maturity, or rather, considerable fragments of a mature erosion surface are still present. This surface is in marked topographic unconformity with the abrupt mountain slopes above the Basin Range faults and with the canyon incisions, and obviously this contrast is due to the Basin Range faulting. On grounds discussed elsewhere in this report (pp. 40 and 77) this prefaulting erosion surface is probably not younger than middle Pliocene nor older than Oligocene, and the principal movements of uplift of the tilted block of the range relative to Rush Valley are presumed to have begun some time in this interval—that is, in Miocene or earlier Pliocene time. The evidence is strong, at least as regards the West Mercur fault, that the movement has continued at intervals practically to the present day.

CAUSE OF THE BASIN RANGE FAULTING

It is obvious that such a major question in geology as that of the cause of mountain formation can never be answered by a study of any single range, but its decision must rest upon a synthesis of material gathered from sources all over the world. However, an ultimate solution of this problem, as well as of any other fundamental problem in geology, must fit the facts of local geology or permit a satisfactory explanation of any discrepancies between fact and theory. An attempt to determine the fundamental cause of the Basin Range faults—that is, the factors involved in the production of the particular orogenic type found in the Oquirrh Mountains—is beyond the scope of this report. It may be appropriate, however, to discuss briefly some of the limitations imposed by the local geologic facts upon a satisfactory theory for the origin of the Basin Ranges, of which the Oquirrh is a typical example. A more detailed discussion is given elsewhere.[14]

It is commonly recognized that the faulting of the Great Basin must be largely independent of the local surficial geology and of local loading and unloading of the crust. The conclusion is so well accepted as hardly to require argument, but it was thought worth while to investigate the matter to some extent.

It has been suggested that erosion from the mountain blocks and deposition upon the valley blocks has led to rising of the mountains and sinking of the valleys in response to isostasy. It is, of course, obvious that such a process offers no key to the cause of the initial faulting by which the mountains were produced, but there can be no doubt that the tendency of the transfer of load is to continue the movement, even though the process must eventually "run down." Ac-

[14] Gilluly, James, Basin Range faulting along the Oquirrh Range, Utah: Geol. Soc. America Bull., vol. 39, pp. 1103–1130, 1928.

cordingly an attempt was made to determine the effect of the tendency.

The first requirement of a test of this tendency is the determination of the rock masses transferred from mountain block to valley block since the inception of the Basin Range faulting. This requires a reconstruction of the prefaulting topography, which in the Stockton and Fairfield quadrangles can only be crudely effected owing to the severe postfaulting erosion on a surface that was originally by no means reduced to a plain. The unevenness of the submature erosion surface obviously offers great difficulties to reconstruction, but it is thought that a surface sloping from 9,000 feet at Soldier Canyon to 8,500 feet at Lion Hill and to 7,300 feet at Alma Young Canyon would fairly represent the general prefaulting topography. Computation of the volume of material inclosed between such a surface and the present one was made from planimeter measurements on contours 1,000 feet apart by means of the end-area formula. The reconstruction of the surface was not considered sufficiently accurate to justify the use of more precise formulas or more closely spaced measurements. Because of inadequate remnants of the prefaulting topography north of Soldier Creek, the computation did not include areas north of the drainage basin of this stream. For the same reason it was impossible to include the east slope of the range. Accordingly the computation was restricted to the area west of the main divide and south of the water parting north of Soldier Creek.

According to this computation about 10.2 cubic miles of rock has been eroded from this district in the present (postfaulting) cycle. The area from which the material was derived is almost 49 square miles, and the average thickness of the amount eroded is thus 0.21 mile, or 1,100 feet. In order to compute the theoretical effect of the addition of this load to the valley block, it is necessary to assume a certain area of deposition. The assumptions were therefore made that the material was all deposited in Rush Valley and that the contributions of the Stansbury and Oquirrh Ranges have not overlapped (or if they have, they have canceled each other), so that the area of the present fans from the Oquirrh Range includes all the deposits of postfaulting age derived from that mass. Such assumptions are conservative rather than otherwise—for instance, it is evident that some material was removed from Rush Valley to Tooele Valley before Lake Bonneville time, but it is thought that such errors would cancel one another if larger areas were compared and that the assumptions stated above will lead to a maximum for the loading effects. In so far as material has left the region, these assumptions will lead to exaggeration of differential load effects.

On these assumptions, then, the 10.2 cubic miles of rock was distributed over an area of roughly 80 square miles, producing an average load 0.1275 mile, or 675 feet, thick. Owing to the lower specific gravity of the alluvium, its thickness as deposited would be greater, perhaps $\frac{2.7}{2.2} \times 675$, or 830 feet, but this would not affect the load involved.

If the mountain and valley areas are regarded as forming a system, the transfer of surface rock from one to the other introduces a tendency for the mountain block to rise in response to the unloading and for the valley block to sink in response to the loading, until, by the transfer of material in the zone of flowage from the loaded to the unloaded block the total masses of the columns above the level of compensation are the same and are equal to their respective masses before the faulting. On the most favorable assumption—that the subcrustal material has the same density as the surface rock transferred—complete local isostatic compensation could account for only $1,100+675=1,775$ feet of the total displacement between the mountain and valley blocks. But from the evidence in hand the average displacement on the fault zone can hardly be less than 3,000 feet and may exceed 5,000 feet. This indicates that local compensation could theoretically account for perhaps one-third to one-half of the observed displacement. As the most severe critics of the idea of crustal competence are willing to grant to the crust strength sufficient to sustain (at least in part) loads of 3,000 feet of rock over an area with a radius of 18 miles,[15] it seems clear, even if there are large errors in the assumptions above made as to volume transfers, that in an evaluation of the causes of the faulting the isostatic tendency between valley and mountain blocks must be considered of entirely subordinate importance in producing the observed displacement between them.

The same conclusion—that individual Basin Ranges are sustained by the strength of the earth's crust—was reached by Gilbert in an entirely different way, from consideration of the loading effect of the water of Lake Bonneville and the lack of response to this loading through faulting such as would be expected on an assumption of local isostatic control of the Basin Ranges.[16]

On any hypothesis of formation of the Basin Range faults, loading and unloading of adjacent blocks could not have occurred until there had been primary faulting to produce the necessary surface relief to bring about erosion. It seems, from the evidence just briefly reviewed and from other considerations, that the ulti-

[15] Bowie, William, On the size of the block of the earth's crust which may be independently in isostatic equilibrium: Washington Acad. Sci. Jour., vol. 14, pp. 355–362, 1924.

[16] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 357–360, 365–392, 1890.

mate cause of first faulting has likewise been the prime factor in continuing the movement.

Whatever the ultimate forces involved in producing the Basin Range faults of the Oquirrh Mountains may have been, this range is so like the others of the Basin and Range province that it seems safe to assume that these forces were operative over the entire segment of the continent between the Wasatch Range and the Sierra Nevada. Several theories have been advanced to account for the orogenic type here represented. The discussion of these theories can hardly be profitable here, but the writer can not refrain from expressing a preference for one of the oldest of them all—that of Gilbert.[17] This theory would explain the ranges by vertical or nearly vertical adjustments of brittle surface rocks to folds induced by regional compression in a deep-seated layer, thus accounting for the lack of correspondence between the fault lines and the preexisting folds of the surface rocks and also for the general parallelism of the ranges over the region as a whole.

FAULTS IN THE STOCKTON MINING AREA

The mining area near Stockton is cut by a great number of faults. Most of these are relatively very small, but a few are of considerable throw. Because of their close connection with the mineralization, all are of prime economic importance.

The faults of this area fall into two principal systems, and there is evidence of at least two periods of faulting in each system. The more prominent as well as the economically more important faults strike between N. 40° W. and N. 40° E., but by far the greatest number strike between much more narrow limits, N. 10°–30° E. Nearly all dip westward at angles between 45° and the vertical, but most of them range between 60° and 70° W. This system is called, in the mining camp, the north-south system; the individual faults and fissures are called crossings. The other fault system is closely related to the attitude of the beds, and the individual faults strike nearly east and dip steeply north. This system is locally called the east-west system.

The earliest fault movement for which evidence was seen occurred on the east-west faults. Little indication of this movement is afforded by the surface exposures, but there is clear evidence in the workings of nearly all the mines, consisting of shear zones developed in the limestones of the Oquirrh formation and locally in the adjoining quartzites, as in the Hampton lease, on the 1,200-foot level of the Honerine mine, where the "St. Patrick" limestone has been cut by a gently curving fault, which passes into the footwall quartzites in both directions along the strike after lying in the limestone for over 400 feet. Other faults of this system rigorously follow a given limestone. Perhaps the most striking example is furnished by the "Galena King gouge," a brecciated and highly altered zone due to shearing and subsequent mineralization of the limestone. The "Galena King gouge" has been recognized from the Argent mine, the most easterly development of the district, almost to the Muerbrook fault, which cuts off the "Galena King" limestone at the mouth of Southport Gulch. Through practically all of this distance of nearly 1½ miles the "Galena King" limestone carries this "gouge" or fault zone, in some places near the footwall of the bed, elsewhere near the hanging wall. The "Hercules" limestone in much of the workings of the Honerine mine shows similar shearing and in places is even completely cut out by faulting subparallel to the bedding. Similar faults have been observed in the "Honerine" limestone near the Palace ore shoot and at the 105 crosscut, as well as farther east at the Wier stopes, all on the 1,200-foot level. These and other east-west faults will be discussed in detail in the mine descriptions, as they are of merely local importance.

As all the faults just mentioned are practically bedding faults and antedate the dike intrusions, it is quite out of the question to prove the amount of movement on any of them. It seems likely, however, in view of the very moderate amount of brecciation that accompanied the faulting, as well as the rather remarkable persistence (with few exceptions) of each fault within a single bed, that the displacements have been very slight and merely such differential movements as must necessarily occur between competent beds in folding. The practical restriction of the faults to the limestones may be accounted for by the relative incompetence of the limestones as contrasted with the strong quartzites between which they lie. On this assumption the faults are contemporaneous with the folding. Similar faults may have been formed in the quartzites, but inasmuch as the mine workings have been confined as much as possible to the limestones, little opportunity was offered to determine the existence of strike faults in the quartzites, and surface indications of such faults are lacking.

The second fault movements took place on the north-south system and are of greater economic importance than any others recognized in the district. An attempt was made in the field mapping to portray these faults, but the scale of the map (pl. 12) is too small to reveal them without confusion, and therefore they are not shown. However, a careful study was made of the displacements of the "Galena King" limestone from the Argent mine to Rush Valley, and in that interval eight faults of measurable displacement were

[17] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 62, 1875.

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seen, and it is quite certain from underground explorations that fissures of this system upon which greater or less displacement has occurred are to be numbered by scores, if not by hundreds.

Inasmuch as the beds dip between 60° and 80° throughout this part of the mining area and the faults are practically dip faults, it is more convenient in this report to refer to the displacements due to these faults in terms of the horizontal separation of the strata than in any other way.

The "Galena King" limestone is faulted in the gulch just west of the Argent mine, the west block being displaced to the north about 150 feet. Another fault cuts it on the east slope of the hill in which is situated the No You Don't tunnel, and here too the west block is displaced to the north about 190 feet. Two small faults, each of which offsets the "Galena King" limestone about 5 to 10 feet, occur on the crest of the hill above the No You Don't tunnel. On each the west block is displaced to the south relative to the east block.

Exposures of the "Galena King" limestone are poor west of the No You Don't tunnel, but the "Paisley" limestone just up the gulch to the north shows a displacement of 40 feet, due to a fault in the bottom of the gulch, the west block having moved south with reference to the east block.

There is no evidence of noteworthy faulting between this point and the Palace crossing, on the hill east of the Galena King mine, and although some of the mining men believe that the Palace crossing is a fault with a displacement at this point of several scores of feet, the writer could find no indication on the surface that it has any such displacement. Indeed, comparison of the maps of the 300-foot level of the Galena King mine with the surface geology seems to offer strong reasons for questioning the existence of any large displacement on this fault here. Yet a denial of the possibility is certainly not warranted, in view of the poor exposures at the critical locality and the demonstrated fact that several faults of this system are rotational, with displacements varying widely from one level to another as well as along the strike. Thus the Palace fault, a thousand feet or so to the south of this point, has a horizontal offset of 40 feet on the 600-foot level of the Honerine mine, the west block being stepped relatively north, while on the 1,200-foot level no offset at all is to be found in the Honerine drift, and the west block is stepped south 8 feet relative to the east block in the St. Patrick drift.

No faults were seen to offset the "Galena King" limestone between the Palace crossing and the west end of the Joe Pull stope of the Galena King mine. At this point the "Galena King" bed on the west block is displaced 20 feet to the south, referred to the east block, but the fault is a scissors fault, because on the 300-foot level of the Galena King mine the displacement is about 30 feet in the opposite sense.

Another small fault offsets the "Galena King" limestone in the gulch just northeast of the air shaft of the Honerine mine and displaces the west block about 20 feet to the north.

The next fault observed was across the gulch west of the Tiptop tunnel of the Stockton Lead Co., where the west block is displaced a few feet to the north.

No other faults were observed between the one just mentioned and the point where the "Galena King" bed passes beneath the alluvium, but there can be little doubt that many other small displacements occur. The Muerbrook fault must be beneath the alluvium, only a few scores of feet from the contact with the bedrock.

The Muerbrook fault probably has a much greater displacement than any of the other north-south faults. Unfortunately, surface exposures are far from satisfactory along the low foothills where this fault occurs, and underground the relations are obscured by igneous intrusion and the accompanying metamorphism of the sedimentary rocks along the line of the Honerine drain tunnel. But the drag exhibited by the "Larsen" limestone west of the Muerbrook mine and by the "Paisley" limestone just north of Southport Gulch is very strong, in the sense suggesting a movement of the west block to the south relative to the east block. Just south of the Black Diamond shaft, west of the portal of the 600-foot level of the Honerine mine, is an outcrop of cherty limestone over 60 feet thick. The only limestone of this character and thickness observed in the entire mining area is the "Paisley" limestone, and the projection of this bed to the drainage-tunnel level makes it seem almost certain that the limestone cut by the drain tunnel west of the Bullion crosscut is the "Paisley" bed and that the Bullion mine is in the "Galena King" limestone rather than in the "Honerine" limestone, as has been assumed by many of the mining men of the district. This interpretation is supported by the character of the section penetrated by the Bullion crosscut and has been arrived at independently by Mr. W. A. Young, of the Combined Metals Reduction Co., and the writer. According to this interpretation, the Muerbrook fault has a displacement of about 800 feet, the west wall having moved south relative to the east.

Innumerable other north-south faults of varying throw are to be seen in the mines, but their discussion can more profitably be deferred to the individual mine descriptions. It can not be safely assumed that all these faults are of the same age, as there has been later movement on faults of this system. However, inasmuch as the great majority of the numerous por-

phyry dikes of this district trend parallel to these faults and some, if not all, of them occupy fault fissures, it is inferred that the larger faults are older than the porphyry intrusions and probably are essentially contemporaneous, and that they are all younger than the east-west faults.

There is evidence in the Honerine mine of at least two periods of faulting later than the porphyry intrusions and earlier than the mineralization. The first of these periods is represented by small north-south faults and shear zones within and cutting along the contacts of porphyry dikes. No satisfactory measure of the displacement along these faults was obtained, but all appear to be minor.

Still later additional movements occurred on some of the east-west faults. These resulted in minor displacements, the observed maximum being 60 feet, cutting porphyry dikes and postporphyry north-south fissures, usually setting the blocks south of the faults westward compared to the blocks north of the faults.

All the above-described faults of the Stockton mining area are older than the mineralization, as shown by the presence in all of undisturbed sulphides. Locally there is some suggestion of postmineral faulting as well, but no evidence was discovered that any postmineral movements were very great. The few occurrences of sheared sulphides are discussed in the descriptions of the mines. The fact that the scarp north of the Stockton Standard prospect, which may be due to Basin Range faulting, is on the strike of the Muerbrook fault has led to the suggestion (p. 84) of possible rejuvenation of movement on this fault in late Tertiary or Quaternary time. With this possible exception it seems likely that nearly all the faults date back to the time of folding and igneous intrusion, presumably early in the Tertiary period.

To summarize the sequence of faulting in the vicinity of Stockton: The earliest faults are bedding faults, presumably accompanying the folding. These were followed by north-south faults formed presumably by subsequent tensional forces. After intrusions of monzonitic porphyries minor north-south and later east-west faulting occurred, perhaps because of readjustments of the roof of a larger magma reservoir below. These faults were followed by the mineralization. Minor postmineral faulting has occurred locally, and possibly the Muerbrook fault was rejuvenated at the time of Basin Range faulting.

SUMMARY OF GEOLOGIC HISTORY

The geologic history of the southern Oquirrh Mountains, as far as it can be deciphered from evidence obtained within the Stockton and Fairfield quadrangles, begins with the area depressed beneath the Lower Cambrian sea and receiving coarse sandy deposits, now represented by the Tintic quartzite. The purity of the quartzite and the absence of shaly detritus or evidence of local channeling support the interpretation that the sedimentation was marine rather than continental.

Toward the end of Lower Cambrian time the area became further depressed, so that instead of receiving coarse sand it began to receive clay—now recognized in an altered condition in the shaly part of the Ophir formation. There is no evidence that the area was exposed to erosion between the Lower and Middle Cambrian epochs. On the contrary, it was probably somewhat depressed, or at least was no longer subject to detrital accumulation but began to receive limy deposits. At first these alternated with clayey deposits, as in the upper part of the Ophir formation, but later the contributions of clay were greatly diminished, so that the lime deposits were only slightly argillaceous. The deposits of this part of Middle Cambrian time are now represented by the Hartmann limestone.

In later Middle Cambrian time an unusual contribution of clastic material, now represented by the basal shale of the Bowman limestone, was received, owing probably to change in relation to the shore line, as indicated by the repeated occurrence of intraformational conglomerates. Several minor repetitions of clay deposition occurred later, but finally the accumulation of limy material again prevailed. If, as has been suggested by several writers, dolomite is derived by the reaction of newly formed calcium carbonate sediments with sea water and hence is favored by slower sedimentation, the area, although still subsiding, did so at a considerably slower rate in the time represented by the Lynch dolomite.

No apparent break in sedimentation occurred between Middle and Upper Cambrian time in this area, and it seems highly probable that conditions continued without change.

Evidence is lacking as to conditions prevailing within the area in the interval between Upper Cambrian and Middle Devonian time. The area may have been the seat of deposition during Ordovician time, as at Tintic, but if so, it was exposed to erosion before the Middle Devonian. It is highly probable that the area was land during the Silurian period. The sea again transgressed over the area probably in Middle Devonian time, depositing as a basal layer a thin veneer consisting largely of reworked Cambrian dolomite but containing little clastic material. The deposition of dolomite was almost immediately resumed, but whether it continued into the Upper Devonian or not is uncertain. Upper Devonian beds do not occur in the area, but they may have been deposited and later removed by erosion.

At some time between the Middle Devonian and the Mississippian the area was uplifted to form a land mass, and upon it was developed a sink-hole (karst) topography in the Jefferson (?) dolomite. The Mississippian submergence that followed was unaccompanied by clastic deposition. Limestone was formed under conditions extremely favorable for invertebrate life, for the deposits of lower Mississippian age carry profuse fossils. It is uncertain whether or not there was an emergent interval between the lower and upper Mississippian, but the phosphatic shales at the base of the Deseret limestone doubtless represent a considerable interval of very slow accumulation.

The area was submerged and sinking at roughly the same rate as the limy sediments accumulated through most of upper Mississippian time, but during a short interval, represented by the Humbug formation, shallower water or stronger currents than usual prevailed and permitted the accumulation of much sandy detritus. Somewhat later, after a time of lime deposition, more clay was deposited, forming the Long Trail shale member.

Toward the end of Mississippian time, after a long time of depression, concomitant with sedimentation, the rate of accumulation of sediments overtook that of depression, so that shallower water prevailed. The sediments became dominantly clastic, chiefly clay but with some sand. It is possible though not certain that the area was emergent for a time. At any rate the early Pennsylvanian sediments are very similar to those of the late Mississippian, both probably connoting shallow-water conditions.

The Pennsylvanian was an epoch of very marked depression. At first the depression was probably rather slow, although the area was probably always below wave base. Later, despite the deposition of vast amounts of sand, aggregating many thousands of feet in thickness, which must necessarily have been laid down rapidly and in a relatively shallow sea, there were interbedded marine lime sediments, which testify to the area having been constantly submerged. This must mean a very rapid depression.

No sedimentary record of the interval between the Pennsylvanian and Tertiary is to be found in the Stockton and Fairfield quadrangles. However, the presence of Permian, Triassic, and Jurassic rocks in considerable thickness in the Park City district,[18] about 30 miles to the east, suggests that at least during part of this time the site of the southern part of the Oquirrh Mountains was receiving deposits. It was probably emergent during most of Cretaceous time, however.[19]

At the end of the Cretaceous or in early Tertiary time the region was compressed in an east-northeast to northeast direction, and the rocks were thrown into large, rather open but somewhat asymmetric, folds with steep northeast flanks. A certain amount of shearing and minor faulting took place during this folding.

After erosion had carved the folded rocks into a somewhat dissected, perhaps even mountainous topography, volcanism ensued, probably in Eocene time. The first volcanic products were breccias and tuffs of considerable thickness, with subordinate flows. The flows became more abundant later in the volcanic history. Although other rocks occurred, latites were predominant, apparently throughout the volcanic activity, at least so far as it is recorded in the rocks preserved to the present time. The irruptive magma finally penetrated even into the previously built volcanic piles. Rhyolite and latite volcanic plugs were intruded and probably added their ejecta to the older flows. Where the magma failed to reach the surface it consolidated into monzonitic rocks.

Probably the force of igneous intrusion was in some places effective in rupturing the previously folded rocks. Perhaps the large faults at Ophir are results of this force. At any rate, after the emplacement of the igneous rocks emanations given off by them, probably chiefly in the hydrothermal condition, brought about considerable metamorphism within the previously faulted rocks, leading finally to deposits of gold, lead, silver, zinc, and copper.

The Oligocene and early Miocene were presumably uneventful periods of erosion with, possibly, the deposition of some coarse grit beds (now represented by fine conglomerate) in low parts of the area. The result of this erosion was the production of a subdued mature surface at the site of the present Oquirrh Mountains. Either in the late Miocene or in the Pliocene epoch faulting began which has continued to the present day. Some of these faults, which are the cause of the topographic prominence of the present range, were probably rejuvenations of earlier breaks dating from the early Tertiary, but others were probably newly formed.

The result of these faults and the accompanying tilting movements has been the rotation of a huge block of the crust, with the uplift of the west edge of the Oquirrh Mountains. Erosion consequent upon this uplift has carved the range deeply, largely destroying the previous mature erosion surface and producing the present rugged topography. Erosion has gone on in the mountains and huge alluvial fans have been built out onto the valleys. Percolating ground water has attacked the ore deposits, oxidizing the sulphides and leading to some slight enrichment.

[18] Boutwell, J. M., and Woolsey, L. H., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 49–59, 1912.

[19] Spieker, E. M., and Reeside, J. B., jr., Upper Cretaceous shore line in Utah: Geol. Soc. America Bull., vol. 37, pp. 429–438, 1926.

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For the most part the valleys have been independent basins, but during at least a brief humid time in the Pleistocene they were united by the waters of Lake Bonneville. There is some suggestion that some valley integration occurred through normal processes before Lake Bonneville time.[20] The small glaciers or snow fields of the higher peaks of the range probably were contemporaneous with the existence of Lake Bonneville. Since Lake Bonneville time the geologic history of the area has been uneventful, with continued erosion in the mountains and deposition in the valleys.

ROCK ALTERATION

PROCESSES

The mineralogic and textural modifications which the rocks of the Stockton and Fairfield quadrangles have undergone subsequent to their cementation and consolidation are included under metamorphism, or the changes which occur below the border zone between the lithosphere and the atmosphere and hydrosphere,[21] and weathering, which occurs in the border zone between the lithosphere and the atmosphere and hydrosphere.

Metamorphism has been of two varieties—dynamic and igneous. To the action of dynamic metamorphism are ascribed such features as fault breccias, which are common throughout the area, and the schistosity of the lower beds of the Ophir formation. Under igneous metamorphism are included all the changes, chemical, textural, or mineralogic, which have been effected in the rocks by the igneous intrusions and the deep-seated solutions associated with them. Among such changes the most important economically has been the formation of the valuable mineral deposits of the area. Igneous metamorphism includes the changes brought about in the country rock and the postconsolidation changes within the intrusive itself. Systematic study of metamorphism by many investigators has resulted in the common recognition of two varieties of igneous metamorphism of the country rocks of an intrusive mass—(1) "normal" metamorphism, involving changes brought about without significant addition of material to the country rocks from the magma; (2) metamorphism involving transfer of material from the magma chamber to the wall rocks. The variety of igneous metamorphism involving material transfer includes what have been called pneumatolytic and hydrothermal metamorphism. The terms "pneumatolytic" and "hydrothermal" imply knowledge of the phase, gaseous or liquid, through which the material transfer occurs. Inasmuch as such knowledge is rarely available and evidence bearing on it is rarely unequivocal, the writer agrees with Ross[22] that the term "pneumatolytic" is better avoided. As the same arguments apply, though less forcefully, against the term "hydrothermal," the present writer believes it best to avoid this term also. In view of the uncertainties as to the criteria of phase relations during metamorphism the noncommittal term "solution" is preferred, without reference to whether the solution is in the gas or the liquid phase. The reasons adduced by Ross seem to compel the belief that truly "hydrothermal" solutions are more important than gas-phase reactions, but the writer does not wish to deny a certain effect to both.

Weathering includes the decomposition and leaching of rocks and ores at and near the surface and the changes involving the deposition at lower levels of the materials taken into solution. Such changes have locally been of considerable importance in separating zinc from lead ores, but on the whole they are not, in this area, of great economic significance.

DYNAMIC METAMORPHISM

Dynamic metamorphism has been rare in the Stockton-Fairfield area. In the description of the Ophir formation on page 11, mention is made of the schistose texture of some of its lower beds as evidence of dynamic metamorphism, perhaps due to the folding of the beds under great pressure. None of the other rocks of the area exhibit any of the characters of dynamic metamorphism and recrystallization, however.

The fault breccias that are so common in the western part of the range are due to friction during the fault movement and crushing of the rocks. Most of them consist of angular fragments of the bordering rock and are of little special interest, but one exposed on the No. 3 level of the Muerbrook mine, at Stockton, is noteworthy as containing well-rounded quartzite pebbles ranging from half an inch to 3 inches in diameter. The rock of these pebbles is almost surely derived locally from the walls of the fault, but the remarkable smooth rounding which they have undergone seems noteworthy.

It is possible that the sericitic gouge which occurs along many faults at Ophir, in Dry Canyon, and in the Stockton district is to be attributed to purely dynamic metamorpshim, but inasmuch as all three of these areas have been subjected to intense activity of circulating solutions which closely followed the igneous intrusions, and there is elsewhere evidence of sericitization by these solutions in the absence of dynamic action, it seems more likely that this sericite along the faults is a product of igneous metamorphism also.

[20] Gilluly, James, Possible desert-basin integration in Utah: Jour. Geology, vol. 37, pp. 672–682, 1929.

[21] This is the definition of Grubenmann and Niggli (Die Gesteinsmetamorphose, p. 179, Berlin, 1924).

[22] Ross, C. S., Physico-chemical factors controlling magmatic differentiation and vein formation: Econ. Geology, vol. 23, p. 869, 1928.

IGNEOUS METAMORPHISM

VARIETIES

Igneous metamorphism as here defined includes all the mineral and textural transformations induced in the solid rocks by the intrusion of an igneous body and the after effects of the intrusion. These alterations are, at least in this area, effected chiefly by the thermal changes due to the intrusion of the highly heated igneous mass and its subsequent cooling and by the chemical changes due to the circulation of highly heated fluids containing material in solution through the rocks. The more influential of these factors in this area has been the transfer of material and heat by circulating fluids as an after-effect of the intrusion.

Metamorphism due to an igneous body is in general both endomorphic—that is, effective within the igneous rock itself—and exomorphic—that is, occurring within the inclosing country rocks. Strictly endomorphic alterations in this area have been slight, most of the metamorphism even of the igneous rocks having been effected by solutions derived from deeper-lying bodies of intrusive rock.

METAMORPHISM WITHIN THE IGNEOUS ROCKS

There have been four chief varieties of alteration of the igneous rocks of the Stockton and Fairfield quadrangles. These are propylitization, sericitization, silicification, and zeolitization.

Propylitization, which involves the alteration of the mafic minerals to chlorite, epidote, and carbonates, the alteration of feldspars to epidote, carbonates, and sericite, and the introduction of pyrite, has been common near the ore deposits of the quadrangles, especially in the immediate neighborhood of ore-bearing fissures. The "Birdseye" porphyry exhibits alteration of this type near the mines on Lion Hill. Propylitization has occurred to a much less extent in the monzonitic rocks of Soldier Canyon but has been the dominant variety of alteration in the Stockton mining area, where hardly a specimen of porphyry can be found that shows no evidence of at least incipient alteration, whereas the more highly mineralized rocks, as in the Honerine mine, have had their dark minerals completely replaced by actinolite, epidote, chlorite, and calcite. The feldspars of these rocks are less altered except immediately adjacent to the mineralized fissures, where the plagioclase has been completely altered to epidote, clinozoisite, sericite, and calcite, although some sericite and carbonate are found in all the specimens collected in the mine. Impregnation with pyrite has been intense.

Sericitization, in which sericite, the fine scaly or silky variety of muscovite, is developed almost to the exclusion of chlorite, etc., has been common throughout the region. The Eagle Hill rhyolite at Mercur, the dike west of Ophir, and the rhyolite cut in the Hidden Treasure and Mono mines are all considerably sericitized. In the Stockton mining area some of the gouge clays along mineralized fissures in the poryhyry dikes consist chiefly of sericite. At some places on Lion Hill the "Birdseye" porphyry has been altered to a white chalky rock which the microscope shows to be a mass of quartz and sericite, heavily impregnated with pyrite. In all these places the plagioclase seems to have been altered most readily to sericite, while the dark minerals have been changed to calcite or chlorite aggregates. More severe alteration results in the replacement of orthoclase by sericite, though this has gone to completion only in small areas. Pyrite and locally quartz, as in the rhyolite in the Hidden Treasure mine, have been introduced at the same time as the sericite. Most specimens show considerable calcite also. Unfortunately, all the specimens that were collected as representative of sericitization had been subject to considerable weathering, with the production of gypsum, iron hydroxides, and clay minerals, so that details of the sericite alteration have been obscured. However, the close association of sericite, epidote, and chlorite in the igneous rocks of the Stockton area indicates much similarity in the composition of the solutions which produced at one extreme a sericite-pyrite-quartz rock and at the other a chlorite-epidote-calcite-pyrite rock with subordinate sericite and with remnants of quartz and feldspar.

Silicification has not been extensive in most of the intrusive rocks of the area, although some quartz has been introduced along the contacts and in joints in the Eagle Hill rhyolite at Mercur as well as in some of the altered monzonitic rocks in the Honerine mine. Silicification accompanied sericitization in the rhyolite of the Hidden Treasure mine. The rhyolite breccia plugs east of Tickville Gulch have undergone very considerable silicification, some of which may, however, be due to weathering only.

Zeolitization has affected only one of the intrusive masses studied—the diorite stock in the east fork of Settlement Canyon. Here late magmatic or hydrothermal reactions have resulted in the replacement of plagioclase and orthoclase crystals by analcite and thomsonite. Narrow veins cutting through the rock have also been filled by these zeolites. The development of zeolites has been widespread in the lava and breccia flows of the Fairfield and Stockton quadrangles. Hot solutions expelled from the lavas themselves (with possibly some meteoric waters) have traversed the rocks and deposited zeolites, chiefly analcite, thomsonite, natrolite, and phillipsite, in innumerable cavities and fissures

METAMORPHISM OF THE SEDIMENTARY ROCKS

METAMORPHISM OF THE QUARTZITES, SANDSTONES, AND SHALES

Igneous metamorphism of the coarser-grained sedimentary rocks of the Stockton and Fairfield quadrangles has in general not been great. Near the monzonitic intrusive rocks of the Soldier Canyon area, where the most intense alteration has occurred, the sandstones and quartzites of the Oquirrh formation show considerable bleaching close to the contacts. In places the bleached zone is 20 or 30 feet wide, especially near the larger masses, although 5 or 10 feet is a more usual measure. Brecciation is common in such sandstone border zones.

Under the microscope these rocks commonly show some enlargement of the quartz grains, though not significantly more than other quartzites not altered by igneous intrusion. Calcite cement between the quartz grains has locally been replaced by diopside and sericite. Nests and veinlets of microcrystalline quartz also occur as metamorphic products. Locally sericite is developed, replacing quartz and detrital feldspar grains. In one specimen the limy cement of the sandstone has been altered, with the formation of a dark-green pleochroic hornblende which penetrates and replaces quartz grains. Fractures through the rock are filled with calcite and, in one specimen, lined with a zeolite whose optical properties correspond with those of epidesmine.

In the mines at Stockton the alteration has been considerably greater. A very light gray fine-grained quartzite at the contact of the "Raddatz" porphyry near the Honerine air shaft shows bleaching and the development of considerable sericite. A hornfels in the Bullion crosscut of the Honerine mine shows, in this section, pronounced fine banding. Rounded clastic quartz grains forming some bands are surrounded by a matrix of calcite and orthoclase, and the intervening bands, which were probably higher in calcite cement, have been altered to irregularly and finely intergrown orthoclase, sericite, epidote, and garnet. Diopside is common in the altered sandstone penetrated by this crosscut. The rock is cut by calcite veinlets in many directions. The sandstone footwall of the "St. Patrick" limestone commonly shows the development of diopside, orthoclase, and colorless chlorite with a little sericite, at the expense of the calcite cement. The original rounded quartz grains of the sandstone are but slightly attacked. A quartzite in the hanging wall of the "St. Patrick" limestone east of the Hampden stope of the Honerine mine shows the clastic quartz much recrystallized into a fine mosaic, and the cement has been altered to diopside, andradite, orthoclase, and apatite. Euhedral calcite rhombs and rhombic crystals of orthoclase (adularia) occur in the recrystallized quartz, and pyrite impregnates the rock thoroughly. A strongly dichroic and birefringent mineral with a mean index of about 1.51 is very plentiful in the quartz mosaic. This is probably beidellite, but its identity is not quite certain. Detrital grains of zircon and microcline appear to have survived the metamorphism unaltered.

Examination of the immediate footwall of the "Honerine" limestone at the Palace ore shoot on the drain-tunnel level of the Honerine mine shows the cement of the sandstone to have been altered, with the production of diopside, orthoclase, and wollastonite. Strongly pleochroic and birefringent epidote, apparently of the pistacite variety, occurs in some specimens. The rock is cut by veinlets of calcite, and locally grains of calcite (ω=1.66) replace quartz. Some garnet, probably of the variety andradite, as its refractive index is clearly higher than 1.85, occurs along these calcite stringers. The detrital quartz has only locally been recrystallized into a fine mosaic. Euhedral crystals of orthoclase (adularia) are sporadically distributed through the quartz aggregate. A little sericite is present in most specimens. Pyrite cubes occur rarely. Similarly altered quartzite of the footwall of the "Honerine" limestone is also present at the Knickerbocker crosscut of the Honerine mine.

The metamorphosed rocks just described occur only in the mineralized area near Stockton and are nowhere far from the fissures along which the ore deposits are localized. There can be no question that the solutions from which the ore deposits were derived and the solutions which induced these alterations in the near-by sandstones were the same.

Similarly altered sandstone is to be seen in Dry Canyon just above the portal of the Deseret incline, where the rock is distinctly bleached. The calcite cement of the rock has been partly altered to diopside. A small amount of orthoclase is also developed, as well as some colorless chlorite. In this area the only igneous rocks exposed are rhyolite dikes and breccias. The metamorphism of the sandstone and limestone in Dry Canyon can not, however, be attributed to these small igneous bodies, for they have produced no similar metamorphism in the country rocks with which they are in direct contact. The alteration must be due to emanations from deeper-lying igneous bodies, not yet exposed by erosion.

No evidence of igneous metamorphism of sandstone has been found farther south in the area except a little sericitization along faults in the Tintic quartzite at Ophir.

Igneous metamorphism has affected shale significantly only in the immediate vicinity of Ophir, for the stratigraphic section contains few shale members and in the rest of the quadrangles they are not associated

with igneous masses. In fact, only the limy shales are altered to any considerable extent. Even at Ophir the metamorphism is not to be ascribed to the small dikes of rhyolite and lamprophyre now exposed. Along the rhyolite dike west of Ophir the Ophir formation shows little change even at the direct contact, where a little rearrangement of muscovite and chlorite is the sole evidence of igneous alteration. The metamorphism of the Ophir shales and the shaly members of the Bowman limestone in Ophir Canyon is localized near the Cliff fault and the fissures extending southward from it. Accordingly it is to be attributed to circulating heated solutions traversing the rocks along these fissures from a deeper-seated igneous mass.

The bed taken as the base of the Bowman limestone is variable. It was originally a mottled limy mudstone with irregular shaly limestone facies. Where least altered, on the east flank of Hartmann Gulch, these facies are clearly recognizable. The dominant facies is dense mudstone breaking with a conchoidal fracture. Even here there is evidence of some igneous metamorphism, for the confused aggregate of muscovite (sericite) and quartz that makes up most of the rock is penetrated by seams of pyrite and considerable pleochroic tourmaline in brown to greenish-yellow needles. As the bed is followed along the outcrop toward the Cliff fault, however, the metamorphism becomes increasingly evident. Reaction has occurred between the more limy and the less limy facies of the original rock, resulting, in some layers, in the segregation of calcite in irregular nodules embedded in silicate minerals. This facies is illustrated in Plate 5, *B*. Other beds of this basal member are dense, nearly massive argillites showing only a faint banding parallel to the bedding.

Under the microscope several varieties of hornfels are recognized. The commonest variety is a dense porcellaneous rock faintly banded parallel to the bedding with light gray and medium brown. The microscope shows the gray bands to consist of orthoclase, in very minute serrate crystals, interlocking in a mosaic of quartz, a little albite, and epidote. The brownish layers are carbonaceous and carry fine grains of epidote (pistacite), quartz, and chlorite. Gradations occur in which orthoclase, epidote, quartz, chlorite, calcite, and carbonaceous matter are all finely intergrown.

Thick beds of massive dense dark-brown hornfels occur in this basal member of the Bowman. The microscope shows them to consist of a matted mass of sericite without common orientation which contains minute grains of orthoclase (locally forming an interlocking mosaic), quartz, and tourmaline and crystals of rutile. The rutile is probably recrystallized sedimentary material, but the elongated needlelike tourmaline is undoubtedly of metamorphic origin. Another variety of hornfels is exceedingly fine grained and consists of bands of quartz and feldspar, probably all of sedimentary origin, separated by bands composed of minute aggregates of sericite, orthoclase, pyrite, and calcite. It is evident on inspection of hand specimens that the principal development of epidote has occurred at the junction of layers of carbonate and siltstone, and this is confirmed by study of thin sections. Minute tourmaline needles are ubiquitous but appear to be more numerous in the darker, more carbonaceous layers than in the lighter ones.

In more limy portions of the member the calcite has been recrystallized. Epidote of a bright-green pleochroic variety is very common, and diopside, tremolite, chlorite, and subordinate garnet (probably andradite) occur. Pyrite is prominent in this facies as well as in the more shaly variety. In all the metamorphic rocks pyrite occurs both disseminated and in veinlets that cut through the other minerals and are undoubtedly somewhat younger than most of the silicate minerals.

Some parts of the basal member of the Bowman limestone show fairly even, very thin banding of more silty and more limy layers. The more silty layers have altered to a mass of epidote, orthoclase, and quartz in which calcite is developed in flat tables parallel to the base. The texture resembles very closely that of the reticulated calcite common to many Tertiary veins.[23] It seems probable that under conditions permitting the formation of adularia the form of calcite tabular parallel to the base is the more stable one.

Alteration similar to that of the basal member has occurred in higher shaly beds throughout the Bowman limestone and, like that in the basal member, has been progressively more intense near the Cliff fault.

The pure shales of the Ophir formation show evidence of igneous metamorphism only near the mineralized fissures, and here the sole effects are the development of a mat of sericite in random orientation and a small amount of blue-green tourmaline. The purer limestones and shales between which these altered limy shales lie show little or no metamorphism except very close to the Cliff fault. It is evident, therefore, that the localization of metamorphism has been governed mainly by the opportunity for intimate reaction between calcite and clay minerals, although the development of tourmaline, iron-rich garnet, and pyrite in the basal member of the Bowman limestone implies the introduction of a minor amount of material from a magmatic source. The chief function of the magmatic emanations, to which the metamorphism was doubtless due, was to furnish the temperature and

[23] Lindgren, Waldemar, Mineral deposits, 3d ed., pp. 521–524, New York, 1928.

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possibly the reacting medium necessary for the reaction betwen the minerals already present in the rock.

It is evident that there can be no sharp line between the metamorphism of a shale containing large quantities of lime and that of a limestone containing large quantities of silt. The Ophir formation contains both varieties, as well as the practically pure shale already described, but for convenience of treatment both of the lime-rich varieties are discussed below, in the section on metamorphism of the limestones.

METAMORPHISM OF THE LIMESTONES

GENERAL FEATURES

Metamorphism of the limestones in the Stockton and Fairfield quadrangles has been localized in comparatively small areas. In general these are the areas in which the mineral deposits occur. Thus metamorphosed limestones are present near Sunshine, Mercur, West Mercur, Lion Hill, Ophir Canyon, Dry Canyon, and Stockton—all localities in which ore bodies have been worked. Some metamorphism has also occurred near the igneous bodies of Soldier Creek, Settlement Canyon, West Canyon, and Tickville Gulch, where no commercial mineral deposits have yet been developed.

In the northerly areas the metamorphosed limestones are closely and directly associated with exposed igneous intrusive rocks, but from Bald Mountain southward such an association is not marked, although igneous rocks are found in small quantity in this part of the range. It is noteworthy, however, that ore deposits and altered limestones in general are confined to portions of the range where at least small bodies of igneous rock occur and are absent where igneous rocks are absent, although many igneous rock bodies have been without significant effect on their inclosing sediments, and many altered masses of limestone are not in direct contact with visible intrusives.[24]

The limestone strata of the area vary notably in susceptibility to alteration. Of the pre-Carboniferous limestones only those of the Ophir formation have been notably altered to lime-silicate masses and ore minerals. The Hartmann limestone shows the sporadic development of tremolite crystals, but ore bodies have not yet been found in any of its beds. The Bowman limestone carries a few small sulphide bodies near the Cliff fault and on the Admiral Dewey claims, but the chief metamorphism of this formation has been confined to the shaly members, whose alteration has already been described. It is true that the alteration of these shaly beds has involved reactions with limestone contained in them, but there has been no significant alteration of the purer limestone beds of the rest of the formation. The Lynch dolomite and Jefferson (?) dolomite have been metamorphosed only very slightly. The striking susceptibility to alteration of the limestones of the Ophir formation is in remarkable contrast to that of the higher beds whose superficial aspect is almost identical. The same especial susceptibility of these rocks has been observed in the East Tintic district, to the south, and in the Cottonwood district, in the Wasatch Range, where great ore bodies have been developed in them.

Of the Carboniferous rocks, the basal few feet of the Madison limestone is much more susceptible to alteration than most of the rest of the formation. Large ore bodies have also been found, however, close to the top as well. The Deseret limestone only locally shows metamorphism, and the same is true of limestones within the Humbug formation. Metamorphism and accompanying ore deposition in the " Great Blue " limestone have been confined chiefly to the portion below the Long Trail shale member, although in a few small areas alteration has occurred in the higher beds. A few of the thin limestone beds in the Manning Canyon shale are locally metamorphosed in Soldier Canyon. The susceptibility to alteration of the numerous limestones of the Oquirrh formation varies greatly. The selective replacement of certain limestone beds by ore minerals while adjacent beds bear none is very marked. The following partial analyses of specimens from the Honerine mine are given by Butler:[25]

Partial analyses of the "Honerine" limestone and the overlying "dolomite"

[R. C. Wells, analyst]

	"Honerine" limestone	"White dolomite"
SiO_2	2. 39	42. 12
CaO	53. 85	29. 20
MgO	. 53	7. 29

Unfortunately, the exact localities from which these specimens were collected are not given, and although it is obvious that the "Honerine" limestone is essentially pure, computation shows that the lime and magnesia of the " dolomite " can not all be combined with carbon dioxide but must be in part in silicates. Accordingly, the " dolomite " analyzed is not an unaltered rock but has already been somewhat metamorphosed. It is probable that the rock is like the white metamorphosed sandstone described on page 94, but with a lower content of sedimentary quartz. Much of the magnesia and lime is probably present in the analyzed rock as diopside, wollastonite, or garnet, which characterize the altered sandstones from the Honerine mine. Nevertheless, the statement of Butler[26] that

[24] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 372, 1920.

[25] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 174, 1920.

[26] Idem, p. 174.

other than purely structural weakness or fissuring of the rock, such as controls the emplacement of sills. It is, however, quite certain that there is no relation between the distribution of the jasperoid and a supposed sill of Eagle Hill rhyolite, as stated by Spurr.[27] In fact, of all the varieties of metamorphism recognized, the alteration to jasperoid shows the least direct relations to the igneous bodies. Certain masses of jasperoid, however, particularly on Rover Hill, are associated with distinct fissures.

The contacts of the jasperoid masses against the country rock are in all observed places distinct and sharp, without transition. Two varieties of silicification associated with ore deposits have been recognized by Irving[28]—one in which the limestone is replaced by the silica through the gradual increase in number of sporadic isolated crystals of quartz and one in which the silicification advances as a wave through the limestone, replacing all the rock as it progresses, thus leading to abrupt contact against the country rock. It is this second and by far more widespread type of silicification that the jasperoids of the Stockton and Fairfield quadrangles represent.

All the jasperoid masses are characterized by jagged brown-stained outcrops. The most casual examination reveals their thoroughly brecciated character. It is doubtful whether a single piece as large as a cubic foot could be found free from slickensided surfaces or shear planes. Some faint suggestions of bedding occur locally, but the fragments exhibiting them rarely if ever conform in attitude to the bedding of the country rock. On the contrary, the laminated fragments are jumbled at all angles. Sporadic angular masses of limestone as much as 3 or 4 feet on a side are embedded in the jasperoid. Much of the jasperoid is broken into angular fragments an inch or less in diameter, forming a rubble that has been cemented into a firm rock. Otherwise massive portions of the rock show "drusy" cavities, invariably coated with white crystalline quartz and commonly filled with coarse calcite. Locally, smooth slickensides as much as 30 feet long cut through the mass. There is no system to be found in these slickensides, as they lie vertically, horizontally, and at any angles between these limits. Many are curved through an arc of nearly 90°. In addition to these larger shear surfaces there are numerous shorter ones which abut sharply against others and terminate. None of these shear surfaces were observed to cut the contact with the country rock, however.

Hand specimens of the jasperoid are light to dark gray or even black and very fine grained to dense, some resembling fine-grained quartzite and some chert. The fracture is correspondingly hackly or conchoidal. Larger masses are chiefly breccias or, if not brecciated, vuggy. The breccia fragments are cemented and veined by white quartz with comb structure. This white quartz is commonly accompanied by barite, either massive or as platy crystals. Many specimens show rebrecciation of the rock and a third generation of quartz that veins and replaces the brecciated baritic jasperoid. Other specimens show brecciation of the early quartz, with its fragments coated by comb quartz and the interstices filled by dark-brown calcite which bears euhedral barite plates. Locally radiating masses of stibnite as much as 6 inches long occur. At other places the vugs of the rock are lined with aragonite in long needles.

Under the microscope the jasperoid shows considerable diversity. Two varieties are most common. One, illustrated in Plate 14, *C*, *D*, is an aggregate of anhedral quartz crystals, all very minute, usually less than 0.03 millimeter in diameter, containing small quantities of apatite and zircon and rather larger quantities of blue-green, strongly pleochroic tourmaline, muscovite plates, and calcite crystals. Epidote, in some specimens in beautiful euhedral crystals, is also common. The quartz granules are all clear except where penetrated by the muscovite plates, and the other minerals occur in general interstitially. This variety is fully 95 per cent quartz.

A second variety (pl. 14, *A*, *B*) has the texture known as the "typical jasperoid" texture. It consists of intergrown quartz grains with a strong tendency to euhedral forms, so that in thin section most of the grains appear bounded by straight lines, and numerous hexagonal and prismatic crystal outlines are present. In some sections the grains are outlined by carbon inclusions; in others they inclose zones of carbonate and epidote crystals. Some sections show secondary enlargement of quartz crystals outlined by such inclusions. Of course, mutual interference of these crystals prevents completely euhedral development. The borders due to secondary enlargement are rarely in perfect crystalline continuity with the main parts of the crystals but almost invariably show wavy extinction. This is apparently due to slightly differing orientation of adjacent segments of the external quartz. There is no reason to suppose, however, that such phenomena are due to mechanical deformation. Tourmaline, sericite, carbonate, carbon, epidote, apatite, and zircon were all recognized in this variety of jasperoid as well as in the anhedral variety. These euhedral quartz grains average probably 0.15 to 0.2 millimeter in diameter, although locally the average grain may be about 0.5 to 0.7 millimeter.

In places these two varieties of jasperoid blend into each other. Where this relation is observed there is

[27] Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 383, 1895.

[28] Irving, J. D., Replacement ore bodies and the criteria for their recognition: Econ. Geology, vol. 6, pp. 555–559, 1911.

commonly a crude wavy streaking in the anhedral facies, which roughly follows the boundary between them. With oblique illumination there is a strong suggestion of colloform banding subparallel to this boundary. Both varieties carry scattered spherules of chalcedony or of quartz outlined by brownish stains which are visible with parallel light but which disappear completely or at least show no crystallographic control when studied under crossed nicols. (See pls. 15, *C*, *D* and 17, *B*.)

Commonly the anhedral variety of jasperoid shows a rough streaking, either curved or straight, along which, either continuously or in small lenses, clear quartz of coarser grain and wavy extinction is developed, in company with barite plates, as shown in Plate 16. These barite plates have gross outlines characteristic of the mineral, but their actual contacts with the quartz are almost invariably serrate and determined by the penetration of minute clear quartz grains into the barite. Here and there divergent masses of stibnite are developed in this variety.

Both the anhedral and the euhedral jasperoid show brecciation and veining by clear colorless quartz, which has strong tendencies to form comblike linings of vugs and veins. This is illustrated in Plate 17, *A*. Barite plates similar to those just described commonly occur in these veins and vugs. The quartz has the divergent extinction characteristic of "flamboyant" quartz.[29] Some of the breccia interspaces are filled with coarsely crystalline calcite.

In a few specimens the jasperoid veined with comb quartz shows further brecciation and veining by brown-stained fine-grained anhedral quartz similar to that described first. This variety of quartz, carrying tourmaline, apatite, carbonate, and zircon, shows in oblique light a very clear banding parallel to the walls of the cracks in which it is developed. The banding is not visible with crossed nicols. This aggregate of brownish quartz and accompanying minerals replaces the older quartz, barite, and calcite masses, penetrating them in wormlike shapes and corroding the already brecciated barite plates very greatly. The flow lines along cracks in barite which it is penetrating and replacing are seen in Plate 18, *A*. They do not appear with crossed nicols. (See pl. 18, *B*.)

To summarize, the hypogene minerals detected in the jasperoid include quartz, chalcedony, barite, calcite, muscovite, tourmaline, apatite, zircon, stibnite, chalcopyrite, epidote, chlorite, carbon, and probably hematite. No silver, arsenic, or lead minerals were detected, although they are closely associated, presumably contemporaneous in origin with the stibnite, and furnish the basis for the commercial importance of this variety of alteration.

[29] Lindgren, Waldemar, Mineral deposits, 3d ed., p. 192, New York, 1928.

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Part of the interpretation placed upon the jasperoid characters described above has been, almost of necessity, implied in their description. However, there are great difficulties involved in the interpretation of the relations observed and the inference from them of a satisfactorily established sequence of events in the formation of the jasperoid masses. One of the most serious difficulties in the way of such an interpretation is presented by the later recrystallization of the original minerals of the rock. One variety of this recrystallization is comparatively simple to understand, though its quantitative evaluation is difficult. This is the recrystallization of spherules of chalcedony to nonoriented anhedral quartz granules. There is no question that this is a common phenomenon, for it has been observed in 6 slides of the 45 examined, and fully half the rest show, though not unequivocally, suggestions of the same process. Another variety of recrystallization offers a greater difficulty to interpretation. It involves the retention of the external form of comparatively large euhedral quartz crystals by aggregates of small, diversely oriented quartz grains. (See pl. 15, *A*, *B*.) This may represent the replacement of the large crystal by the small ones, a process for which no chemical or physical reason is discernible; or the recrystallization of the large crystal into the confused aggregate of small ones, which is equally difficult to understand; or, finally, the solution of the quartz of the original crystal and the subsequent filling of the resultant vug by the finer quartz mosaic, which seems likewise unreasonable, as the matrix of the original quartz crystal is also quartz and would hardly be expected to retain the cast of the dissolved crystal long enough to permit the change. No solution of the enigma has been reached, but the fact of the retention of the form of seemingly undistorted quartz crystals by mosaics of small diversely oriented grains is apparent and must throw doubt on any interpretations of the origin based upon the present grain of the rock. However, within the limitations just discussed, the following hypothesis of the origin of the jasperoid is advanced.

The first stage in the formation of the jasperoid was the replacement of the limestone by colloidal silica. Direct evidence for this is limited to the spherules of chalcedony and the associated wavy color banding, both of which are considered metacolloidal. Where crystallization ensued immediately after deposition of this colloidal precipitate, the anhedral fine-grained quartz rock was formed, but where conditions favored a more leisurely crystallization, the euhedral quartz crystals grew and to a large extent excluded from themselves the impurities present in the mass, resulting in coarser-grained aggregates of clear quartz outlined by the impurities. This process would presumably lead to the convexity of the contact of the euhe-

dral quartz areas against the anhedral areas and the wavy lines of excluded impurities along this contact.

During the gel stage the mass was largely hydrous, soft, and yielding, and upon beginning of crystallization a considerable loss of volume ensued. The shrinkage of the mass due to this process opened cavities, either analogous to miaroles or continuous fissures, and as a result the mass was brecciated. Into the cavities thus formed and along bands whose relations resemble the well-known diffusion bands of Liesegang and which may have originated in a manner controlled by a somewhat analogous process fresh siliceous material gained access to the rock, in company with considerable barite. These minerals filled the crevices in the rock due to brecciation, and there is considerable evidence that the barite locally replaced the gel as well as the fine-grained anhedral metacolloidal quartz. The evidence for replacement of the gel by barite is illustrated in the specimen shown in Plate 16, *A*, where a brecciated crystal of barite is embedded in fine anhedral quartz showing no brecciation. The easily identifiable plate form of the barite is considered evidence, though not conclusive, of its replacement origin, although the serrate borders are interpreted as indicating that the final crystallization of the gel in which it is embedded was delayed beyond the time of emplacement of the barite. Similar phenomena are common through the specimens examined. In some places there may be doubt that the fine quartz aggregate in which the barite breccia is embedded is older than the barite, and indeed in many places there is evidence of a still later quartz generation which replaces the barite breccia as a whole. This is shown by the occurrence of brecciated barite in which fine-grained anhedral quartz is injected, as indicated by flow lines visible in oblique light, as illustrated in Plate 18. But in the examples previously described this possibility seems excluded by the fact that the fine aggregate containing the brecciated barite is apparently continuous with a larger mass that is definitely veined by the clear quartz and accompanying barite.

Although in general the barite is euhedral against the clear quartz accompanying it, there are places where it is corroded by the quartz which is euhedral against the barite, all within the same veinlet through the jasperoid aggregate. No difference in age is discernible between the two minerals. Some of the quartz of this second generation shows remarkable strain twinning strongly resembling the twinning of microcline. (See pl. 19, *A*.) This twinning is found only in a few grains lining open spaces in the breccia, and their peculiarities are difficult to interpret. They seem to be governed by slight shearing along prism faces and the basal plane. They resemble some of the deformed quartz illustrated by Holmquist,[30] though not identical with any he describes. The explanation of their origin preferred by the writer is that they resulted from the crystallization of chalcedony which had been deformed and whose fibers had been deoriented.

There is some doubt as to the age of the stibnite and chalcopyrite aggregates relative to the several generations of silica, but it seems probable that they accompany the second generation of silica and the first of barite. The calcite present in megascopically visible amounts is later than the second generation of silica and fills vugs coated by it. The calcite is in turn, however, penetrated and replaced by veinlets of quartz and fine euhedral plates of barite. (See pl. 19, *B*.) The second generation of quartz offers almost no evidence within itself of colloidal origin, but in one place colloform banding was observed. Elsewhere the quartz is clear and carries no tourmaline, sericite, apatite, or zircon. Barite and a little calcite with probably the stibnite and accompanying pyrite are the only impurities it contains.

However, after the cementation of the brecciated quartz of the first generation by the clear quartz and barite of the second generation, further brecciation ensued, and a third generation of quartz, accompanied by barite, tourmaline, sericite, apatite, and zircon, penetrated all the older rock and replaced the mass with blending contacts. This generation of material exhibits the colloform banding so clearly that there can be little doubt of its colloidal origin.

The following epitome of the origin of the jasperoid is suggested:

1. Replacement of the limestone along fissures and bedding surfaces by colloidal silica, accompanied by tourmaline, apatite, zircon, and calcite.
2. Partial crystallization of the colloidal mass leading to the formation of openings by shrinkage and to brecciation.
3. Filling of these openings by a mass of perhaps colloidal silica, barite, and stibnite. Partial replacement of this quartz and the gel of stage 1 by barite.
4. Continuing crystallization of the colloidal mass of stages 1 and 3, inducing further fracturing of the barite and the quartz of stage 3.
5. Introduction of calcite, filling vugs, and veining of calcite by quartz.
6. Introduction of colloform silica accompanied by tourmaline, apatite, sericite, zircon, and calcite.
7. Introduction of small amounts of muscovite and considerable epidote, chiefly along fissures in the rock.

It is possible that the stage numbered 7 took place earlier than indicated, and it is also possible that there was a still later deposit of calcite lining the vugs and

[30] Holmquist, P. J., Zur Morphologie der Gesteinsquarz—II: Geol. Fören. Förh., Band 48, Heft 3, pp. 410–428, 1926.

cavities of the jasperoid, but these questions have not been decided. Also there is no information as to the stage at which the carbon, which is so widespread in these jasperoids, was introduced.

The suggestion advanced above of colloidal origin of the silica deposit is similar to that offered by Lindgren [31] for the jasperoids of Tintic. However, the evidence at Mercur and Lion Hill is not nearly so clear as that at Tintic, as no large colloform masses of silica are now observable. It is only in the residual spherules of chalcedony and the faint banding of colloform shapes through the rock that evidence of the postulated colloidal stage is discerned.

It might be considered very questionable whether colloidal silica could be deposited at temperatures high enough to permit the deposition of tourmaline. Nevertheless, tourmaline occurs in close proximity to apparently primary spherules of chalcedony in several slides. With caution urged by the undoubted evidence of recrystallization in the rock it can not safely be stated that the tourmaline is contemporaneous with the chalcedony, but if it is later the recrystallization of the chalcedony during the tourmaline stage has been incomplete, and the possibility that it is older than the chalcedony is negatived by the widespread distribution of both minerals through a common matrix of quartz. Furthermore, the barite of the second stage is locally invaded by tourmaline-bearing quartz which carries colloform evidences. This throws some doubt on Lindgren's statement [32] that the absence of chalcedony and other evidences of a metacolloidal origin of the jasperoid in the southern part of the Tintic district is due to the high temperature prevailing there at the time of ore deposition, for he records no tourmaline or other high-temperature minerals from this portion of the jasperoid. It seems probable that other factors than temperature are involved in determining the boundary between colloidal and crystalline precipitation of silica.

Although the stages listed above have been traced with a fair degree of confidence in the specimens studied, it is highly improbable that they were synchronous throughout the deposits, or even that every portion of the jasperoid underwent this history. On the contrary, it is very likely that the crystallization and brecciation of the early deposited gel was accompanied by constant renewal of the supplies of silica. A closely connected or even continuous series of contributions of silica may appear as apparently distinct contributions merely because of local changes in the supply of material, probably influenced to a large degree by the brecciation due to crystallization and shrinkage of the gel. The only conclusions as to variations in the supply of material which seem to be established are that barite and stibnite are not found in the earliest silica except as presumable replacement products and that calcite is abundant only in the late stages.

[31] Lindgren, Waldemar, Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 154–159, 1919.
[32] Idem, p. 158.

ALTERATION TO LIME SILICATES AND ACCOMPANYING SULPHIDES

Small masses of lime silicates are widespread in the Stockton and Fairfield quadrangles. They are found at Mercur, near Chloride Point, at Ophir, in Dry Canyon, in Soldier Canyon, near Stockton, in Settlement Canyon, in Middle Canyon, and in Tickville Gulch. They occur chiefly at the contact of igneous intrusive rocks and their inclosing limestones but locally occur isolated from any visible intrusive masses.

There are considerable variations in the susceptibility of the different strata to metamorphism of this type. Although inescapable evidence of the introduction of some extraneous material to the rocks during the metamorphism has been found, there is no doubt that the formation of lime silicates is governed chiefly by the presence of impurities in the limestone. A similar feature has already been remarked with respect to the metamorphism of the sandstones, quartzites, and shales. (See pp. 94–95.) It is probable that the rather rigorously selective metamorphism of certain limestones to the neglect of their neighbors is based chiefly upon such differences in composition.

Thus, large bodies of lime silicate rock have been developed in the limestone members of the Ophir formation at Ophir, but the overlying Hartmann limestone remains essentially unaltered except along very local fissures. Similarly at Stockton certain limestone beds in the Oquirrh formation remain completely unaffected by metamorphic processes that have transformed their neighbors to solid lime silicate masses. Despite this selective action, practically every limestone formation in the area has at some place been metamorphosed to lime hornfels in greater or less degree.

In addition to the stratigraphic control, this variety of metamorphism is largely confined to fissured portions of the limestones. Thus, in massive limestones the metamorphism is ordinarily limited to a zone only a very few feet wide directly at the contact of the intrusive mass, but where the rock has been fissured, affording paths of easier access for the solutions, the metamorphism extends much more widely. In general, the lime silicate masses directly associated with intrusive rocks are much lower in sulphide content than those which are localized along fissures.

Lime hornfels masses directly along igneous contacts.—The limestones of the Oquirrh formation at the contact of the hypersthene diorite porphyry mass in Tickville Gulch have been altered through a zone a

few feet wide into dense green aphanitic porcellaneous rocks which the microscope shows to consist chiefly of diopside, quartz, and a little pistacite. The contact zone is narrow.

The quartz diorite stock on the divide between Settlement and Middle Canyons has a similar narrow hornfels border consisting chiefly of the grossularite garnet (n=1.74) and vesuvianite.

The diorite stock in the east fork of Settlement Canyon has altered the country rock considerably and has formed in it actinolite, pink orthoclase, quartz, analcite, and garnet (n about 1.85, hence near andradite). The garnet occurs in veins that are bordered by actinolite and orthoclase, and the analcite is later than all these minerals.

The most prominent lime hornfels masses directly bordering intrusive bodies in the area are those on the north wall of Soldier Canyon. Inclusions of the limestone near the border of the largest intrusive here are considerably altered by reaction with the magma, and fragments are strewn through the igneous rock. These consist chiefly of diopside, slightly altered to uralitic amphibole, pistacite, and pyrite. The lime hornfels masses surrounding the stock are about 150 feet in average width but locally attain 300 feet. Outside the zone where the silicates have been formed the limestones show some marmarization but to a much smaller distance. The width of this contact aureole is very striking in view of the small size of the exposed stock, which is in some places hardly as wide as the combined contact zones. It seems highly probable that the relatively great width of the contact aureole is due to the widening of the stock downward. Indeed, this is indicated by the exposed contacts in the ravines. Most of the lime silicate rocks are dense, porcellaneous, and light gray with a slight greenish tinge. They are practically aphanitic in hand specimens and break with hackly or conchoidal fracture. Under the microscope the average grain size of these rocks is seen to be about 0.02 millimeter. The dominant mineral is wollastonite, with diopside, orthoclase, quartz, and titanite as subordinate but abundant constituents. Some pyrite occurs locally, interstitial to the wollastonite. Where diopside is more plentiful the rock is more conspicuously green in color. Locally the hornfels is somewhat coarser grained, with average grain size about 0.1 millimeter, and exceptional sporadic masses of limestone carry large euhedral green grains of diopside as much as 3 millimeters long. Just at the border of the igneous mass the hornfels consists largely of diopside, pistacite, vesuvianite, and andradite. The garnet and vesuvianite are chiefly localized along fissures and in vugs, a fact which suggests that their formation was dependent upon the transfer of material to the rock from the intrusive.

The smaller sills near the large stock have similar though very much smaller contact aureoles. The rocks are as a rule exceedingly fine grained, and the minerals are difficult of determination, but diopside, wollastonite, quartz, pyrite, and a little muscovite were found, with considerable calcite remaining.

The smaller igneous masses south of Soldier Canyon have very small contact zones in the limestones which they cut. A little epidote is present along the lamprophyre dike on the Admiral Dewey claims, above Ophir, and some garnet and diopside occur in the hanging wall of one of the monzonite sills on the saddle east of the Chloride Point mine. The Eagle Hill rhyolite at Mercur has metamorphosed the limestone it intrudes and produced a rock containing garnet, fluorite, sericite, and quartz for a few inches from the contact. Some tourmaline has also been developed. The effect of the Eagle Hill rhyolite has on the whole, however, been very slight.

Hornfels masses not directly along igneous contacts.—The hornfels masses just described are significant scientifically as indicators of the metamorphosing effect of the several intrusives but are of little or no economic importance. Similar rocks, not in direct contact with any igneous masses but localized along faults and fissures, are, on the contrary, of great commercial importance, because of the very common association of deposits of lead, zinc, and other metals with them. There are three principal areas within the Stockton and Fairfield quadrangles where such lime hornfels masses deposited along fissures are found. These are the Stockton mining district, Dry Canyon, and Ophir.

In the mining area near Stockton there are considerable bodies of lime silicate rocks, localized chiefly along fissures but to a smaller extent along the larger monzonite intrusives, such as the "Raddatz" porphyry in the Honerine mine. In the sections exhibited by the crosscuts in the Honerine mine a very large proportion of the limestones intersected have been altered to silicate minerals.

Along the drain-tunnel level of the Honerine mine, near the "Raddatz" porphyry, lime silicate rocks occur. Typical specimens vary from chalky white to greenish dense aphanitic rocks, veined with pyrite and, less commonly, galena and sphalerite. Under the microscope the rocks are seen to consist chiefly of wollastonite, actinolite, diopside, quartz, calcite, and garnet, with apophyllite, orthoclase, apatite, zircon, titanite, and muscovite as less prominent components. The garnet (n slightly higher than 1.90, probably indicating a titanium-bearing andradite) occurs chiefly as veins through the wollastonite rock. Calcite occurs both as a residual mineral poikilitically inclosing the other minerals and in veins through them. Some veins of antigorite and small veinlets of quartz penetrate

the rocks. Sulphides, where present, appear to be definitely associated with fissures, commonly the same ones as are followed by the garnet. Some few specimens carry a little plagioclase near the composition $Ab_{70}An_{30}$. At the mouth of the St. Patrick crosscut metacrysts of wollastonite fully 1 centimeter across are common in this variety of hornfels.

Very similar rocks occur in the copper drift and the Bullion crosscut of the Honerine mine. In the Bullion crosscut orthoclase-rich hornfels also was found, and both epidote and fluorite occur in it. Sepiolite and a clay mineral resembling beidellite occur as alteration products of these rocks.

In the Knickerbocker crosscut of the Honerine mine the "Honerine" limestone is a dark-gray, coarsely crystalline, essentially pure carbonate rock, but the limestone immediately overlying it has been metamorphosed into a diopside-wollastonite-zoisite rock with some andradite, fluorite, orthoclase, and apatite. Some quartz occurs in certain beds of the altered rock.

Other localities in the Honerine mine at which lime silicate rocks were collected include the 1,600-foot level in the hanging wall of the 1,640 stope; the tunnel level in the "Honerine" limestone east of the Wier crosscut; the hanging wall of the Palace shoot, just above the drain-tunnel level; and many places in the crosscut to the Tip Top mine. As is evident on computation of the analysis quoted on page 96, the rock from the hanging wall of the "Honerine" limestone called "dolomite" by Butler, is actually a silicate rock similar to those just described. Similar rocks also occur in the footwall of the "Galena King" limestone of the Tip Top mine at the 700-foot level and in the hanging wall at the portal of the Tip Top tunnel, as well as near the Calumet and Muscatine mines, toward the south end of the Stockton mining area.

In Dry Canyon lime silicate rocks are less conspicuous than they are near Stockton; nevertheless, they are found at many places. In the lower tunnel of the Mono mine, along the Corbon No. 1 fault, the Deseret limestone has been altered to a rock consisting of coarsely crystalline calcite, actinolite, sericite, and quartz, veined by seams carrying pyrite, chalcopyrite, sphalerite, and galena. In the fractures cutting these sulphide veins later quartz and calcite have been deposited.

Some diopside-wollastonite rock occurs in the Deseret incline, and considerable was found on both the Dry Canyon and Ophir Canyon sides of the Hidden Treasure and Cliff mines. Along the Cliff fault in the lower tunnel of the Cliff mine the Lynch dolomite has been metamorphosed to a diopside-tremolite rock that carries a little residual calcite and is veined by talc, which has been derived by alteration of the diopside and tremolite. Some wollastonite occurs here also, but it is not prominent. A mineral resembling marialite but too fine grained for certain determination is also present. Small veins of pyrite, sphalerite, and a little galena penetrate the rock.

Along the West Side stopes of the Hidden Treasure mine considerable lime hornfels occurs. The rocks are dark green, aphanitic, and impregnated by seams of galena, sphalerite, and pyrite. The minerals composing the rock are diopside, actinolite (formed by alteration of the diopside), orthoclase, apatite, muscovite, garnet (n about 1.85, near andradite), chlorite (an alteration product of diopside, garnet, and actinolite) and sulphides. The sulphide veinlets also carry much garnet. Calcite is residual and incloses most of the other minerals where the silication has not proceeded to completion.

On the Sovereign tunnel level at the second crosscut east of the Hidden Treasure incline chert nodules in the limestone have furnished opportunity for metamorphism by reaction. The center of one chert nodule that was studied is recrystallized into a quartz mosaic, inclosing rosettes and aggregates of wollastonite and diopside. This is surrounded by a confused aggregate of wollastonite, then by radiate wollastonite fibers several millimeters in maximum length. The whole is set in a coarse calcite matrix, containing little knots of quartz and wollastonite scattered through it. Orthoclase and a very little pistacite, together with carbon which is concentrated in wavy streaks subparallel to the outline of the chert nodule, also occur. No sulphides are present here.

In a stope above the Sovereign tunnel level, in the lower part of the Deseret limestone, several silicate minerals occur. The limestone is rich in phosphates, chiefly collophane, which has partly recrystallized to apatite. Diopside (somewhat altered to actinolite), quartz, orthoclase, epidote, sericite, andradite garnet, and probably marialite also occur in this rock, which superficially is apparently unaltered blue limestone and effervesces freely in cold dilute acid.

The most conspicuous association of lime hornfels with fissures and with sulphide ores in the Stockton and Fairfield quadrangles occurs at Ophir, on the north side of Ophir Canyon, in and around the Ophir Hill Consolidated mine. The limestone beds in the upper part of the Ophir formation have been altered adjacent to the Cliff fault and a group of related north-south fissures, and the ultimate product of the metamorphism consists of the ore bodies worked in the Ophir Hill mine. The surface exposures are not good, but in conjunction with the east (7½) drift on the "Copper bed" at the drain-tunnel level in the Ophir Hill mine they give a fairly good opportunity to trace the alterations of the limestone into ore.

The unaltered limestone of the Ophir formation is impure, discontinuous shaly bands running through it and giving it a mottled appearance. Where fresh

the shaly layers are a darker brown than the purer limestones, a contrast that is heightened by weathering. The microscope shows that the rock is made up of calcite layers carrying a few flakes of muscovite, with chlorite and carbon, together with silty layers rich in muscovite, apatite, carbon, and a little pyrite. An analysis of the rock is given in column 1 of the first table on this page.

Toward the ore bodies the rock becomes more coarsely crystalline and slightly more quartzose. An analysis of such a rock is given in column 2 of the table. At about 250 feet east of the No. 2 stope in the "Copper vein" limestone the banding is still more pronounced and the rock is somewhat lighter in color. It is composed chiefly of calcite, but muscovite, quartz, orthoclase, and chlorite are prominent constituents, and epidote, rutile, tourmaline, and pyrrhotite occur. An analysis of the rock is given in column 3 of the table. It is evident that the rock shows decreasing carbonate and calcium content and increasing silica, alumina, and potassa. This is reflected in the quantitative mineral composition given in the table at the bottom of this page.

About 25 feet east of No. 2 stope on the drain-tunnel level of the Ophir Hill mine the "Copper vein" limestone is strongly mottled with white, green, and gray bands and lenses and is veined with pyrite and pyrrhotite. Under the microscope the rock is seen to be strikingly different from those above described. Calcite remains more abundant than any other mineral but constitutes only about one-third of the rock. Orthoclase, in very minute grains, averaging perhaps 0.02 millimeter in diameter, forms a mosaic carrying quartz grains and rosettes of sericite in considerable quantity. Epidote is an abundant constituent of the rock, being closely associated with the calcite. Its crystals, many of them beautifully euhedral, reach 0.2 millimeter in length. Chlorite mats are associated with them. Rutile, apatite, and pyrite are subsidiary constituents. A hand specimen of this variety of rock is illustrated in Plate 20, *A*. Its analysis is given in column 4 of the table.

Still closer to the fissure along which the stope is localized the rock is altered to sulphide ore. Under the microscope its nonsulphide constituents are seen to be orthoclase in rhombic crystals (adularia), quartz exhibiting a strong tendency to form euhedral crystals as much as 1 millimeter long, sericite, chlorite, calcite, fluorite, zircon, rutile, and apatite in short prismatic grains. The sulphides show a tendency to be molded on the euhedral quartz crystals (see pl. 20, *B*) and to replace quartz and all the other minerals. The analysis of this ore is given in column 5 of the table.

The mineral composition of the rocks of the series just described, deduced from microscopic study in conjunction with the chemical analyses, is given in the second table below. This table shows the increase in silicates and sulphides and the decrease in carbonates during the metamorphism.

Chemical analyses showing metamorphism of "Copper vein" limestone of the Ophir formation, in the Ophir Hill Consolidated mine

[J. G. Fairchild, analyst]

	1	2	3	4	5
Specific gravity:					
Particles	2.760	2.782	2.762	2.724	3.841
Lump	2.760	2.758	2.758	2.716	3.591
Porosity (calculated)	0.00	1.00	0.10	0.20	6.50
SiO_2	1.05	22.67	32.73	37.08	19.22
Al_2O_3	1.20	4.96	11.65	11.14	7.60
Fe_2O_3	.38	.97	1.19	1.35	.96
FeO	1.96	2.73	2.73	1.42	1.80
MgO	4.31	2.17	4.16	1.92	2.26
CaO	48.18	35.55	24.57	21.80	2.47
Na_2O	Trace.	Trace.	Trace.	.15	.59
K_2O	.12	1.59	3.92	7.00	3.68
H_2O-	.05	.00	.14	.06	.00
H_2O+	.05	1.42	.70	.80	1.62
TiO_2	.00	.25	.50	.50	.20
CO_2	41.66	27.30	17.12	14.75	1.99
P_2O_5	.03	.26	.12	.25	.35
Cl	.03	.02	.11	.03	Trace.
F	[a]	[a]	[a]	[a]	.25
S	.05	.56	.33	.17	.80
MnO	.25	.10	.10	.20	.35
FeS_2	.37	Trace?	[a]	1.50	26.39
PbS	[a]	[a]	[a]	[a]	14.37
ZnS	[a]	[a]	[a]	[a]	15.07
Cu	[a]	[a]	[a]	[a]	.40
Ag	[a]	[a]	[a]	[a]	Trace?
	99.69	100.55	100.07	100.12	100.37
Less O=S or F	-------	.28	.17	.08	.51
	99.69	100.27	99.90	100.04	99.86

[a] Not found.

1. Practically unaltered limestone, about 400 feet east of No. 2 stope, 7½ east drift.
2. Slightly altered limestone, about 300 feet east of No. 2 stope, 7½ east drift.
3. Banded, more altered limestone, 250 feet east of No. 2 stope.
4. Mottled green, white, and gray hornfels, 25 feet east of fissure in No. 2 stope.
5. Ore in hornfels, 10 feet east of fissure, No. 2 stope.

Mineral composition (percentage by weight) deduced from microscopic studies and chemical composition of the analyzed rocks listed in preceding table

	1	2	3	4	5	5a
Calcite	74.8	62.5	38.9	33.5	------	------
Dolomite	20.2	------	------	------	4.3	10.5
Muscovite	.8	13.5	18.3	6.1	9.6	23.6
Quartz	------	13.9	12.0	9.5	------	------
Orthoclase	------	------	10.0	26.7	20.2	49.4
Epidote	------	------	2.9	15.1	2.1	5.1
Chlorite	2.9	6.7	17.0	5.4	3.0	7.3
Apatite	.1	.7	.3	.3	1.0	2.4
Rutile	------	.3	.5	.5	.2	.5
Pyrrhotite	.2	1.6	.8	.4	------	------
Magnetite	.7	1.4	------	------	------	------
Pyrite	.4	------	------	1.5	25.7	------
Galena	------	------	------	------	14.4	------
Sphalerite	------	------	------	------	17.3	------
Chalcopyrite	------	------	------	------	1.1	------
Fluorite	------	------	------	------	.6	1.4
	100.1	100.6	100.7	99.0	99.5	100.2

The computed mineral composition of the first four of the rocks above represented agrees well with the composition as estimated from study of thin sections. No. 5, however, appears from microscopic study to carry considerably more free quartz than is permitted by any possible combination of the chemical components of the rock found in the analysis. It also carries more epidote than chlorite, which, if computed from the chemical analysis, would cause a decided deficiency in silica. Both of these discrepancies are believed to be due primarily to the impossibility of obtaining a representative sample of sulphide-silicate rock and secondarily to difficulty in duplicating samples of powder with such large differences in density as well as to inevitable errors in so complex an analysis. Undoubtedly there is considerable quartz in the rock, perhaps as much as 6 or 8 per cent. Chlorite is somewhat lower than the above computation shows, and epidote somewhat higher. However, the analysis undoubtedly reveals a continuation of the chemical transfers indicated in the earlier part of the series, as is clearly seen in column 5a, which represents the composition of the nonsulphide portion of No. 5 on the approximate assumptions of the mineral composition shown in column 5.

Although the series of changes just described as shown by the "Copper vein" limestone of the Ophir Hill mine is believed to be representative of the rest of the mine, it does not embrace all the rock varieties found. Locally, the metamorphism leads to replacement of the original limestone by quartz, with orthoclase and sericite as practically the only silicate minerals. A trifling amount of tourmaline was found in such a specimen.

At some places a banded and mottled hornfels occurs which carries essentially pure andradite (refractive index 1.89 ± 0.01) in beautifully euhedral crystals with orthoclase and epidote. Calcite is residual and also occurs as veins cutting all the silicates. Pyrrhotite, pyrite, galena, and sphalerite occur interstitial to the garnet and epidote and locally replace them. (See pl. 23, *B*.) The sulphides have a decided tendency to favor certain layers, producing a lenticular stratiform arrangement.

Diopside occurs in some of these garnet-bearing rocks. It is everywhere euhedral against the calcite in which it is embedded.

In some places near fissures tongues of epidote and white calcite rock, roughly parallel to the bedding, penetrate apparently unaltered limestone. Such tonguelike masses are usually accompanied by pyrite, which is rather rigorously limited to them, being practically absent from the gray limestone. A little quartz, in small part euhedral, is commonly associated with such pyrite. In some specimens such tongues of replacement minerals appear to have been guided by carbonaceous layers in the limestone, for carbonaceous seams occur in the middle of them. It is probable that such seams afforded zones of greater permeability for solutions penetrating the rock, though it is possible that they furnished a chemical cause of localization.

All the varieties of hornfels described above are conspicuous and common in the Ophir Hill mine, but the dominant variety is a conspicuously banded, very strikingly mottled rock. The rock is green, white, and brownish gray, with very systematic arrangement of the bands. (See pl. 21, *A*.) The brownish-gray layers are traceable directly into the mottled layers of less altered shaly limestone, and it is clear that the green bands similarly represent the alteration of the limestone.

Under the microscope the brownish-gray layers are seen to be composed almost wholly of minute muscovite plates, oriented for the most part parallel to the bedding of the rock, though some of them are arranged in rosettes or transverse to the bedding. Few of these mica plates reach a length of 0.03 millimeters. A little orthoclase and epidote occur in these altered shale layers, and a trifling amount of pyrite, which may be of sedimentary origin, is also found. The layers probably owe their brownish-gray color to the presence of minute carbonaceous flakes.

The clear-white layers that everywhere border these shale layers are shown by the microscope to consist almost wholly of minute grains of orthoclase, which rarely attain 0.1 millimeter and average perhaps 0.01 millimeter in diameter. Muscovite, epidote, and some carbonaceous material occur in the orthoclase layers but in quantities so small that they can not be seen to affect the white color of the layers. A little plagioclase, probably oligoclase, was seen in three or four slides. The boundaries between the white orthoclase layers and the brownish-gray muscovite layers are, in general, parallel to the bedding, but closer study shows that this is only an approximate parallelism—the contact is serrate in detail.

The green layers, which represent the alteration of the purer limestone parts of the rock, consist chiefly of epidote, in crystals reaching 0.6 millimeter in length but averaging perhaps 0.1 millimeter. Locally these crystals constitute the entire layer but generally they are set in a coarsely crystalline calcite matrix. A little orthoclase and muscovite occur in these layers. Considerable quartz and chlorite also occur here and there, but these are believed to be chiefly due to a still later phase of metamorphism. Such quartz masses commonly inclose euhedral crystals of epidote and adularia. (See fig. 13.)

The hornfelses described above have furnished the country rock for ore of three different varieties—fissure fillings, impregnations, and massive sulphides.

There are two chief varieties of fissures along which the sulphides occur. Those of one variety are clean cut, are nearly vertical, and form the central fissures of the ore shoots that have been mined. Several of these fissure veins cut cleanly the massive replacement ore that makes up the chief ore of the mine, but their central positions in the stope are nevertheless convincing evidence of their genetic relations to the replacement ore. A hand specimen illustrating the clean cutting of replacement ore by such a vein is illustrated in Plate 21, *B*.

These central veins rarely exceed 2 inches in width and for long distances may be individually less than a quarter of an inch, though where they are so narrow

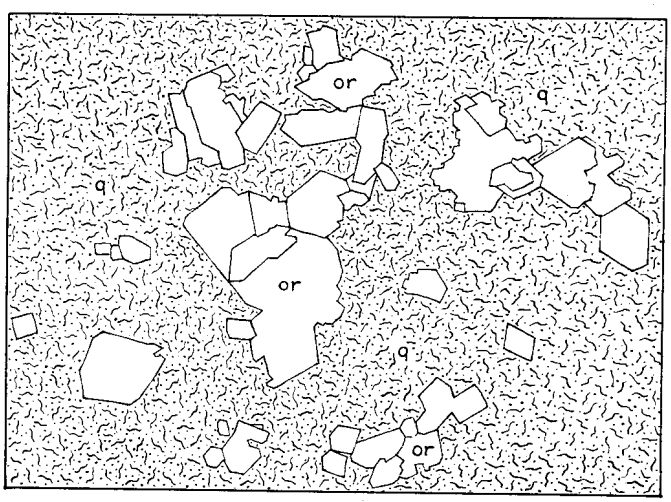


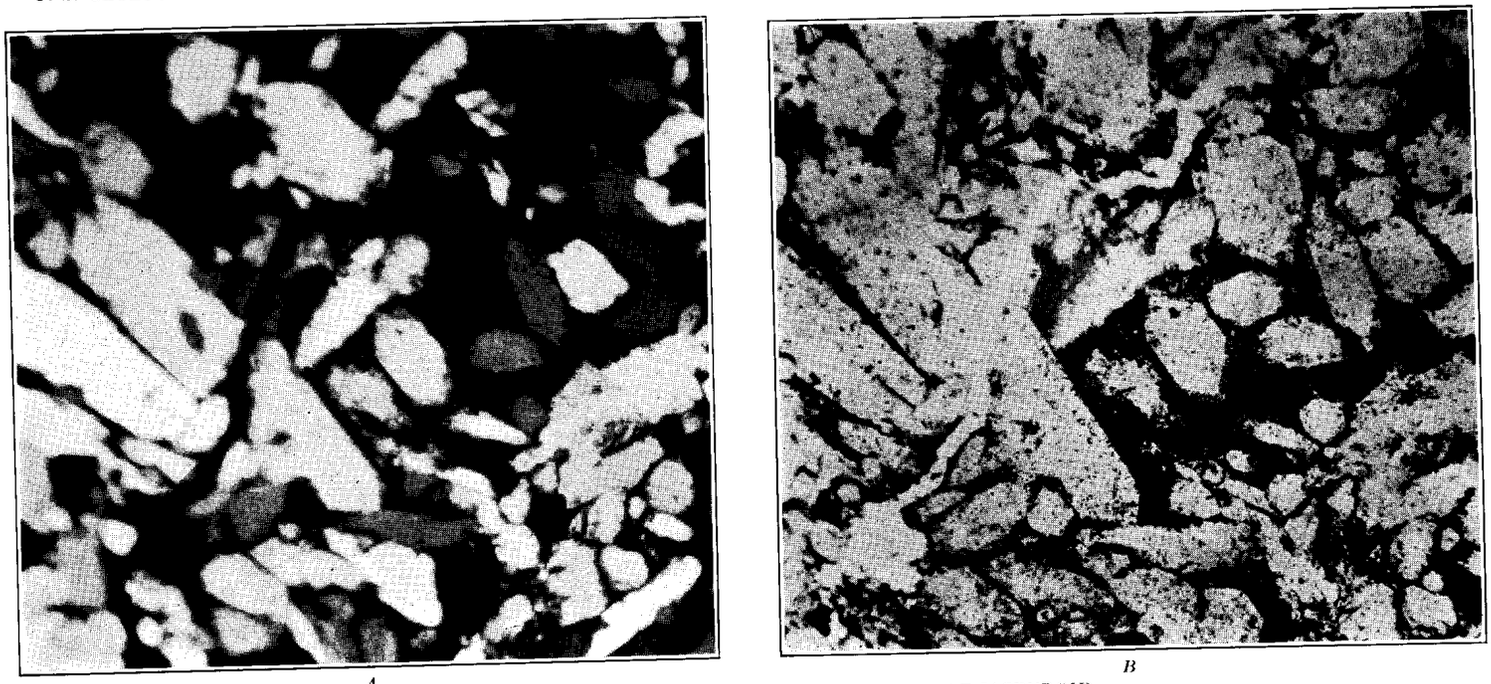
FIGURE 13.—Tracing of photomicrograph, showing euhedral orthoclase (adularia) crystals inclosed in quartz groundmass. Enlarged 260 diameters

there are usually several veins. They consist chiefly of pyrite in a carbonate matrix, the whole veined with galena, sphalerite, chalcopyrite, and considerable tennantite. The paragenesis appears to be manganiferous dolomite, pyrite, tennantite, pyrrhotite, galena and sphalerite, chalcopyrite, sericite, with locally a late generation of tennantite and, finally, a late generation of slightly manganiferous dolomite. Exceptionally the veins carry a little quartz and orthoclase as very early minerals. The early dolomite has commonly been almost completely replaced by sulphides. The manganese content of the early dolomite, as indicated by refractive indexes and by bead tests, amounts to only a few per cent. A little manganiferous calcite also occurs, but its relation to the other minerals is uncertain.

In addition to these generally clean-cut major fissures there are many small, anastomosing irregular veinlets penetrating the hornfels in innumerable directions. At places where the alteration to hornfels has been incomplete epidote is concentrated along such veins, both as a veneer of the fracture surface and replacing the country rock. Pyrite almost invariably accompanies the epidote. Where the alteration to hornfels has led to complete silication of the rock, these veinlets are filled with pyrite, dolomite, chalcopyrite, a little pyrrhotite, galena, sphalerite, quartz, and, less commonly, fluorite. In these stringers, as well as in the larger fissures, the manganiferous dolomite is commonly early and replaced by pyrite. Galena, sphalerite, and chalcopyrite replace the pyrite, and fluorite, where present, replaces these sulphides. Locally there is a second generation of dolomite. Sericite is commonly a very late mineral. It is interesting to note that pyrite commonly replaces the rock along such fissures, and although the later sulphides do so locally, they are much more closely limited to the fissures themselves.

Close to these fissures the hornfels has been in places decidedly sericitized. The residual calcite, epidote, orthoclase, and muscovite have been attacked and replaced by fine mats of radiating sericite. The sericite is commonly accompanied by pyrite and quartz, but it has also attacked and embayed older quartz and pyrite. In general, it may be said that the sericitization was later than the epidote-orthoclase formation and later than at least a part of the sulphide deposition. This is evident from the manner in which the sericite rosettes are embaying and replacing the pyrite-galena mass shown in Plate 22, *A*.

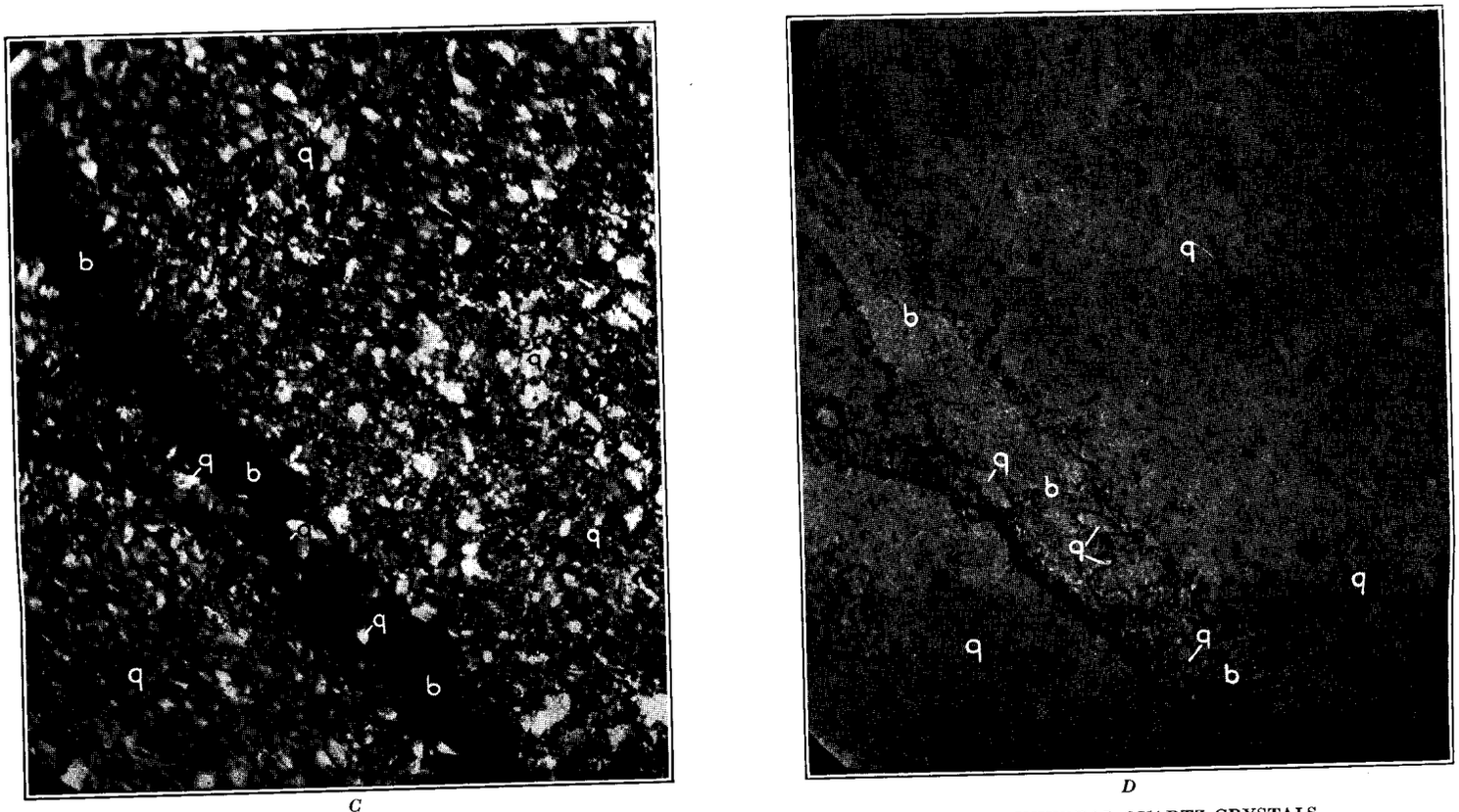
The sulphides, in addition to cutting through the hornfels as veinlets, occur as impregnations through it. Of these impregnating sulphides, pyrite is decidedly the most widespread. Pyrrhotite is common, together with sphalerite, galena, and chalcopyrite. The galena contains sparse microscopic blebs of argentite. All the sulphides show a marked preference for the epidote rock as host, and it is rare, indeed, to find galena or sphalerite in the muscovite or orthoclase varieties, but pyrite and to a less extent pyrrhotite and chalcopyrite are less rigorously confined to the epidote layers. Fluorite and dolomite are occasionally found with the impregnating sulphides. The impregnating pyrite is commonly euhedral and in individual crystals, but the other sulphides usually occur as rounded or lenticular aggregates. Locally this lenticular habit of the sulphides leads to a decided banding of the rock. (See pl. 22, *B*.) In places, though by no means everywhere, this lenticular habit can be referred to the replacement of carbonate lenses in the hornfels. The carbonate itself is probably usually a replacement mineral, occurring chiefly in the middle of the epidote layers but in places at the borders. Such a specimen showed, under the microscope, replacement of the carbonate by euhedral quartz prisms, with sulphides molded on the quartz and to some extent replacing it as well as carbonate. Seri-



A *B*

A, B. "TYPICAL JASPEROID" TEXTURED VARIETY OF JASPEROID

The interstices between quartz crystals in this specimen, though not in most, are filled with carbon. *A*, Crossed nicols; *B*, plain light. Enlarged 86 diameters.



C *D*

C, D. ANHEDRAL VARIETY OF JASPEROID, VEINED WITH BARITE THAT CONTAINS EUHEDRAL QUARTZ CRYSTALS

C, Crossed nicols; *D*, plain light. q, Quartz; b, barite. Enlarged 81 diameters.

cite is the latest mineral, replacing all the earlier ones. The paragenesis is carbonate, quartz, pyrite, galena and sphalerite, sericite.

The replacement of the epidote bands by sulphides was not confined to the calcite masses, however, but proceeded throughout the layers. In the ore bodies themselves the sulphides have replaced the entire epidote layer, resulting in an ore consisting of sulphides with remaining bands of muscovite and orthoclase running through it. (See pl. 23, *A*.)

Such ore is crudely banded parallel to the bedding, as a result of variations in the amounts of the different sulphides. The sulphides were nearly always accompanied or preceded by a small amount of carbonate. Pyrite is the earliest sulphide, being veined and replaced by galena, sphalerite, and chalcopyrite. The pyrite has a strong tendency toward euhedral form, but the other sulphides show very slight tendencies of this kind. Locally pyrrhotite, accompanied by chalcopyrite, is the dominant sulphide replacing pyrite and is itself replaced by galena and sphalerite. The sphalerite invariably contains minute blebs of chalcopyrite. These are shown by reflected polarized light to be composite, each bleb made up of several diversely oriented grains. The blebs are arranged along cleavage directions in the sphalerite and along grain borders. Whether they are due to replacement or to unmixing of solid solution of chalcopyrite and sphalerite is unknown, though the constancy of the relationship seems to favor the latter hypothesis.

In some of these ore-bearing banded hornfels masses the orthoclase bands show later replacement by calcite in plates developed parallel to the base. This crystal form is very probably the form of calcite stable at high temperatures. Its common association with rhombic orthoclase has been pointed out by Kalb.[33]

In a few places the metamorphism of the limestones in the Ophir Hill Consolidated mine has resulted in the production of small vugs in which many beautifully euhedral crystals of various minerals were developed. Among the most remarkable of these vugs are some in the wall of the Wild Delirium stope in the "Copper vein" limestone. Euhedral pyrite furnishes support for some remarkable tetrahedrons of tennantite fully 2 centimeters on an edge. Beautifully formed galena crystals, developed along the octahedron, form blades 1 centimeter across and are in part covered by clean-cut, brilliant twinned chalcopyrite crystals. Dolomite, in flat rhombohedrons and rosettes, prismatic quartz, and very unusual acutely scalenohedral calcite, as well as the common flat rhombohedral calcite, were found in such vugs. In one specimen examined euhedral wurtzite coats tennantite, along with dolomite and calcite. Large rhombs, 1 centimeter on an edge, are pseudomorphed by minute rhombs of siderite which form a very porous mass. Whether the original large rhombs were solid siderite or some other carbonate is unknown.

Paragenesis during hornfels metamorphism.—The paragenetic relations of the minerals of the lime silicate rocks are not clear in detail. Recrystallization has proceeded to such an extent close to the ore bodies that it is not possible to determine whether the rock has passed through the successive stages of mineralogic change that are now indicated in proceeding from unaltered limestone to ore or whether the present relations are due to the temperature gradient away from the central fissures. Thus the exterior zones of altered rock are rich in muscovite and chlorite, while the interior zones are in general rich in orthoclase and epidote, but it is impossible to prove whether or not a rock that is now composed of epidote, orthoclase, quartz, and muscovite ever passed through a phase of development during which it contained chlorite and muscovite as its sole noncarbonate constituents. Thus it can not be asserted that epidote was developed later than chlorite but merely that it was more stable at the higher temperatures prevailing during metamorphism. Epidote represents a higher ratio of ferric to ferrous iron than chlorite.

On this basis, then, garnet, epidote, diopside, orthoclase, and quartz belong to an inner zone of higher temperature and greater material transfer, whereas chlorite and muscovite, although found in the inner zones, are characteristic of the border of alteration, where less metamorphism has occurred and presumably lower temperatures prevailed. Some sericite is definitely later than all other silicate minerals and definitely replaces them as well as the sulphides in a few localities close to the fissures. Probably this replacement occurred during a fall in temperature in a late stage of the mineralization. Quartz is also a late mineral in places.

Whatever may be the age relations among the silicates, it is quite certain that in general the sulphides and carbonates were deposited later than the silicates, for they vein the garnet-epidote-orthoclase rocks in every specimen examined and inclose and embay the individual silicates in a way that is convincing of their later formation. Among the sulphides, pyrite appears to be the earliest as well as to have traveled most widely; pyrrhotite, galena, sphalerite, and chalcopyrite are later. The mutual relations of the three last-named minerals are not such as to prove any age difference between them, except that locally the chalcopyrite veins galena and is thus later. There is also a suggestion that sphalerite began to be deposited

[33] Kalb, Georg, Die Kristalltracht des Kalkspates in minerogenetischer Betrachtung: Centralbl. Mineralogie, 1928, Abt. A, No. 10, pp. 337–339.

slightly earlier than galena. The minute argentite blebs are apparently limited to the galena and are probably contemporaneous with it. Tennantite is present in very small quantities, some earlier than galena and some apparently later. Carbonates preceded, accompanied, and followed the sulphides. These paragenetic relations are summarized in Figure 14.

ALTERATION TO SULPHIDE ORES AND ACCOMPANYING GANGUE

Replacement ore.—As appears inevitable in the classification of natural phenomena, there is no sharp division between the alteration of limestone to hornfels and accompanying ore minerals and the alteration of limestone to sulphides with few or no lime silicates.

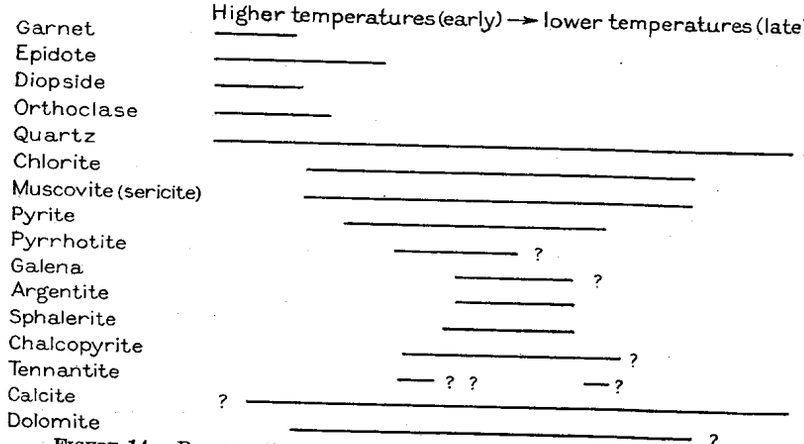


FIGURE 14.—Paragenetic relations of minerals in hornfels ore at Ophir

However, although hornfelses and accompanying sulphides are widespread in the Stockton and Fairfield quadrangles, the only mineral deposit of importance that is characterized by the dominance of lime silicate gangue is that of the Ophir Hill Consolidated mine, at Ophir. The ore deposits of commercial value, with the exception of the jasperoid ores such as those of Mercur, Sunshine, and Lion Hill and the lime silicate ores of the Ophir Hill Consolidated mine, are characterized by the comparatively narrow zones of alteration of their wall rocks.

The principal localities where the metamorphism of limestone to sulphides has occurred are in the mining area near Stockton, in Dry Canyon, and Ophir Canyon, and on Lion Hill. The local features that appear to have exercised control in bringing about this metamorphism are fissuring of the rock and the presence of a susceptible limestone bed.

The remarkable localizing control exercised by the fissures is very strikingly seen in the mining area near Stockton. Here the country rock is sliced by a multitude of essentially north-south fissures, most of which dip steeply west. Many of these fissures are faults, but others show no measurable displacement. Many are coated by greater or less quantities of pyrite and galena, although some are barren. Where these fissures penetrate limestone beds of the Oquirrh formation they commonly are bordered by sulphide masses in the limestone. Sulphide masses also occur along stringers making out from these fissures into hornfels, quartzite, porphyry, or unaltered limestone. There has been little mineralization in the area that can not be directly referred to visible fissures, and the probabilities appear overwhelming that if exposures were sufficient all the sulphide bodies would be found to be related to fissures or other especially permeable passageways.

Where the east-west limestones are cut by strike faults and fissures, as they are in the Hampden stope in the "St. Patrick" limestone and the Palace shoot above the 1,200-foot level in the "Honerine" limestone in the Honerine mine and in the "Galena King" limestone in the Galena King and Tiptop mines, the stopes are especially large. However, no considerable ore body that is not related to the north-south fissures has been found in this area, so that strike faulting in itself can hardly have sufficed for the localization of the ore bodies. Presumably this is due to lack of persistence of the strike faults, which probably originated by shearing during folding. The north-south fissures, standing essentially parallel to the compressive forces, gaped open and furnished continuous channels for the metamorphosing solutions.

The fissure control in the localization of sulphide bodies is not quite so conspicuous in the mines of Dry Canyon, doubtless in part because of greater oxidation and consequent obscuring of relations in the accessible portions of the deposits. Even here, however, the linear disposition of the ore bodies strongly suggests fissure control during ore deposition. Similar evidence is found in the Hidden Treasure and Cliff mines and in the Buffalo tunnel, on Lion Hill.

In addition to the fissure control of sulphide replacement there has been an apparent stratigraphic control. It is only exceptionally that the sandstone, quartzite, and shale in the area are replaced by sulphide ores, although this has occurred in the Kearsarge mine, in Dry Canyon, and in the Salvation-Hercules mine, in Ben Harrison Gulch. Even among the limestone beds there is great variability. Certain beds are very susceptible to replacement and others are not, although no chemical or physical differences between them are readily discernible. Probably there are intrinsic differences in susceptibility between the different limestones, but the irregularity in the replacement seems more commonly to depend upon physical factors than

upon chemical factors. The conspicuous shearing along bedding planes in several of the larger ore bodies gives rise to the suspicion that the varying susceptibility to replacement of the different limestone beds may be due chiefly to variations in fracturing of the beds. This can not be proved, however, and until that is done it seems permissible in the discussion of ore localization to distinguish between evident fissures and differences in susceptibility of the limestone beds.

The "Honerine," "St. Patrick," "Galena King," "Ben Harrison," and "Black Bear" limestone beds of the Oquirrh formation are conspicuously more susceptible to metamorphism than the other limestones in this part of the stratigraphic section. In the Dry Canyon area the beds at the top of the Deseret limestone contain the ores of the Deseret and Queen of the Hills mines, and the beds just below the Long Trail shale member of the "Great Blue" limestone have been the sites of sulphide replacement in the Mono and Brooklyn mines, in Dry Canyon, and in the Buffalo tunnel, in Long Trail Gulch. Similarly the beds at the top of the Madison limestone contain most of the ore in the Jim Fisk mine, in Ophir Canyon, and the Hidden Treasure mine, in Dry Canyon. The Cliff mine, however, is developed in beds low in the Madison limestone, and the Chicago ore shoot is very irregular and is not limited to any particular limestone bed. These ore-bearing limestones do not differ conspicuously from their neighbors, yet the markedly selective replacement they have undergone certainly indicates some distinctive feature about them, of fundamental economic importance.

The replacement of these limestone beds by sulphide ores is localized along fissures and for the most part within certain beds. The sulphide replacement bodies are only rarely, however, of the full thickness of the limestone host, but occur as podlike masses, usually exhibiting their maximum thickness along the fissures and narrowing away from them. Commonly the termination of the replacement body is of smoothly rounded outline, but veinlets of sulphides are occasionally seen which extend in stringers along the limestone beds away from the more massive bodies. Where the replacement has been essentially complete to the full extent away from the fissure, the stopes have been extended to its limits, but where the sulphide bodies terminate in replacement veinlets and stringers the economic limitations on mining have resulted in leaving the small stringers in the stope walls. Commonly the alteration of the wall rocks along these sulphide bodies has been very slight, resulting merely in a small amount of sericitization and silicification. Adjacent strata are locally altered to lime silicate hornfels (see p. 105), but only rarely does the bed that has undergone sulphide replacement show also the hornfels variety of metamorphism.

The size of these replacement masses is variable, although the variations within any one mass are not, as a rule, very irregular. Some of the replacement bodies exceed 100 feet in strike length, although this length is exceptional and rarely maintained for any great distance along the pitch of the body. The pitch length of the replacement bodies is also variable, but the Palace shoots in both the "Honerine" and "St. Patrick" limestones have been followed to depths of 1,600 feet, corresponding to pitch lengths of over 1,800 feet, and the pitch length of the Hidden Treasure stope is over 1,600 feet. All gradations in size occur down to and below the minable limit. It is noteworthy, however, that variations in cross section along the pitch within any single body are generally gradual.

The sulphide replacement bodies are commonly massive and are composed chiefly of pyrite, galena, and sphalerite, with subordinate amounts of chalcopyrite. The galena contains a very few microscopic blebs of argentite. The sulphides rarely show banded structure except where the replacement has terminated in stringers that are roughly parallel to the bedding. Where replacement has been complete banding is generally inconspicuous. In some places there is a crude tendency for the pyrite to form a shell about a central core of galena. This arrangement is visible in the Palace shoot in the "Honerine" limestone just above the drain tunnel of the Honerine mine but is not a constant feature. The most striking feature of the sulphide replacement masses is probably their variability in mineralogy, a single shoot changing capriciously along its length from a galena-rich to a sphalerite-rich mass. There is, however, considerably more zinc than lead in the Dry Canyon area and considerably less in the Stockton area.

The mineralogy of the sulphide replacement is very simple. Quartz, sericite, calcite, and locally a little epidote are the only gangue minerals of consequence in most of the deposits, and they are probably much subordinate quantitatively to the sulphides. Fluorite is a prominent constituent of the ore from the Buffalo tunnel and the Queen of the Hills mine. Pyrite is probably the most plentiful sulphide, because of its widespread impregnation of the limestones in small bunches, but in the more massive replacement bodies galena and sphalerite predominate. Chalcopyrite is locally plentiful but is absent from many shoots. Arsenopyrite occurs in small quantities but is reported to be locally plentiful. Tetrahedrite is reported by Butler[34] as a minor constituent of the ore at Stockton but was not found in the specimens studied by the writer. It must be very subordinate.

[34] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 372, 1920

The paragenesis of the minerals in these sulphide bodies is as follows: Quartz began to be deposited earlier than the other minerals, followed by sericite. Pyrite is in general the oldest sulphide but locally replaces the others, proving its long-continued deposition. Chalcopyrite is ordinarily slightly later than the first pyrite and commonly is associated in intimate intergrowth with sphalerite but in some specimens clearly cuts galena and sphalerite. Galena and sphalerite are of essentially the same age, but in places there is a suggestion that the galena is a little later than the sphalerite. Elsewhere the sphalerite replaces the galena. In the fluorite-bearing replacement bodies fluorite is later than galena. Calcite is both earlier and later than the sulphides, being, like quartz and sericite, a persistent mineral. These paragenetic relations are summarized in Figure 15.

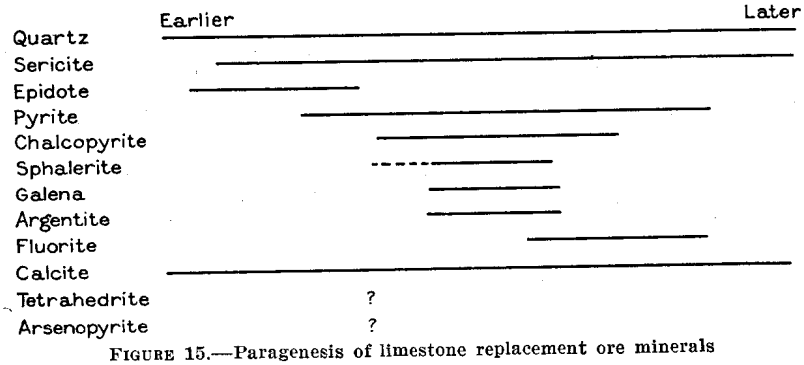


FIGURE 15.—Paragenesis of limestone replacement ore minerals

Locally the ore shows postmineral brecciation. This is especially conspicuous in ore from the Ben Harrison mine, from the Connor stope of the Honerine mine, and from the Maybell mine, all in the Stockton area. It is not believed that such brecciation is due to strong faulting, however.

Fissure ore.—Closely associated with the sulphide ores that have just been described as due to replacement of the limestones are the sulphide ores that are due not to replacement but merely to fissure filling. Strictly speaking, these are not directly the products of rock alteration, but because they represent the feeding fissures traversed by the solutions that metamorphosed the limestones to ore, they will be discussed here.

These fissure ores are essentially identical in composition with the limestone replacement ores just described. They are essentially sulphide ores, containing chiefly pyrite, sphalerite, and galena, and low in quartz and calcite (which is locally manganiferous). Some of the mining men believe these fissure fillings to be higher in tetrahedrite and arsenopyrite than the replacement ores. The writer was unable definitely to confirm this opinion, but inasmuch as the fissure ore associated with the hornfels in the Ophir Hill Consolidated mine is higher in tennantite than the replacement ore, there seems to be some foundation for it. The fissure ores undoubtedly carry more gold than the replacement ores, assays as high as $19 a ton having been reported on ore from the Wier fissure, in the Honerine mine. In the Salvation-Hercules and Kearsarge fissures even higher assays have been reported.

Locally this fissure ore is of sufficient value to be mined, as in the Salvation-Hercules, Kearsarge, and Jim Fisk mines, but practically all the economically important deposits are of replacement origin.

ALTERATION TO DOLOMITE

In addition to the principal varieties of metamorphism of the limestones which have been described above, a small amount of dolomitization has also been effected by igneous emanations and is appropriately considered here. The extensive dolomite beds of the area, as stated on page 16, are attributed to alteration during or shortly after deposition and not to igneous metamorphism.

Most of the small amount of dolomitization considered below is confined to the Ophir Hill Consolidated mine. At several places in this mine, instead of the usual hornfels and sulphide products, the metamorphism has altered the limestones of the Ophir formation to dolomite. An effort was made to ascertain whether or not a zonal distribution of the dolomite was discernible with reference to the sulphides and silicates associated with the fissures of the mine, but its distribution appears to be sporadic. Small lenses of brecciated, veined, and vuggy dolomite occur along the borders of the stopes, but more commonly the stope walls are formed of lime silicate rocks.

The small masses of dolomite are mottled gray, buff, and white. Close inspection shows that the gray masses are residuals of the original limestone, now entirely replaced by pyrite and dolomite. The buff veinlets are chiefly sericite, and the white veins that pass through the whole mass are all dolomite. The vugs in these rocks are lined with dolomite. An analysis of such a rock is given below:

Analysis of dolomite replacing limestone of Ophir formation, 7½ drift, No. 2 stope, Ophir Hill Consolidated mine

[J. G. Fairchild, analyst]

SiO_2	3.97	CO_2	42.48
Al_2O_3	1.56	P_2O_5	.03
Fe_2O_3	Not found.	Cl	Trace.
FeO	2.12	F	.75
MgO	16.28	S	.03
CaO	30.16	MnO	.59
Na_2O	.10	FeS_2	1.57
K_2O	.33		100.51
H_2O-	.02	Less O=S or F	.32
H_2O+	.16		100.19
TiO_2	.00		

Specific gravity: Particles, 2.854; lump, 2.710. Porosity, approximately 5 per cent.

The mineral composition of this rock, as computed from the analysis and checked against the microscopic study, is as follows:

Dolomite	83.6	Pyrite	1.6
Calcite	7.0	Pyrrhotite	.1
Muscovite	4.0	Apatite	.1
Quartz	2.2		
Fluorite	1.6		100.2

The dolomite is slightly ferriferous and manganiferous. The calcite is probably residual from the original limestone.

In some specimens the dolomite is massive, veined, and partly replaced by sulphides, orthoclase, and quartz. (See pl. 24.)

THEORY OF IGNEOUS METAMORPHISM AND ORE DEPOSITION

AGENTS OF IGNEOUS METAMORPHISM

The intrusion of an igneous mass introduces at least two factors—heat and mineralizer-rich solutions—which tend to alter the country rocks. Pressure conditions are also changed, in general, but this change can hardly be very effective in metamorphism associated with near-surface intrusions, dominantly of crosscutting character, although it is doubtless of primary importance in deep-seated intrusions, especially with those of concordant type. The intrusions of the Stockton and Fairfield quadrangles were emplaced at rather moderate depths in the earth's crust. (See p. 69.) It seems permissible, therefore, to neglect the pressure effects of the magmatic movements as metamorphic factors, although it will be necessary to consider the vapor pressures developed during magmatic differentiation.

In view of these considerations, the igneous metamorphism of the Stockton and Fairfield quadrangles is attributed to the action of heat and of heated solutions of magmatic origin. Although it is possible that the country rocks themselves supplied a considerable amount of water to assist in the changes, in view of the strong mineralogic evidence of magmatic affiliations of the solutions and the adequacy of the magma as a source, it is believed unnecessary to consider the contribution of water by the country rocks.

"Normal" contact metamorphism involves, by definition, no significant addition of materials to the country rock from the magma. The metamorphism is due to heat and to the presence of solutions that serve as reacting media for the materials already present in the rock. The heat effect, however, can not be attributed solely to the conduction of heat through the walls of the magma chamber, as is clearly evident both in this area and in many others, because, if it were, the width of the aureoles of "normal" contact metamorphism would depend primarily upon the size of the igneous masses, not upon such factors as the inclination of the contacts, the structure, and the rock texture. The field facts suffice to show that even "normal" contact metamorphism rests, finally, upon the transfer of heat by solutions.

The igneous masses exposed at the surface are not believed to be the sources of more than minor amounts of the heated solutions that effected the metamorphism. They have themselves also suffered considerable alteration, and in the Bingham area, just north of these quadrangles, changes involving addition and subtraction of materials on a great scale have been effected within the related porphyry there exposed.[35] The sporadic distribution of metamorphism and the occurrence of isolated metamorphic rocks, such as those at Ophir and Dry Canyon, which are not in contact with any intrusives now exposed, lead to the same conclusion.

These facts seem to require the reference of the metamorphosing solutions and the now exposed porphyries to a common source at somewhat deeper levels in the crust than those now accessible to observation. This larger igneous mass must be considered as having been emplaced at high temperature, in the condition of mutual solution of silicate-forming constituents with a moderate content of mineralizers. It is theoretically necessary that in any system not completely closed (and in nature a completely closed system is unthinkable) such a liquid phase must be accompanied by a vapor phase tending toward equilibrium with it. The work of Morey[36] has given grounds for the belief that the vapor pressures during high-temperature stages of magmatic history are rather moderate, and losses of volatile constituents from the magma would accordingly be moderate also at any considerable depth in the crust. Obviously, any movement of the magma body to higher levels in the crust would, through reduction in the external pressure acting on the magma, lead to increased loss of the vapor phase. As has been emphasized by Spencer,[37] such loss of volatile constituents must result in higher concentration of silicate-forming materials in the residual liquid phase. This in turn would induce crystallization of these nonvolatile constituents, which by increasing the concentration of volatiles in the liquid, would lead to further increase in vapor pressure.[38] Cooling, of course, would also act in the same direction, the crystallization of silicates

[35] Boutwell, J. M., and Keith, Arthur, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pp. 162–172, 1905.

[36] Morey, G. W., The development of pressure in magmas as a result of crystallization: Washington Acad. Sci. Jour., vol. 12, pp. 219–230, 1922.

[37] Spencer, A. C., Geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, p. 61, 1917.

[38] Morey, G. W., op. cit., pp. 223–230.

leading to progressive increase in the vapor pressure at equilibrium with the liquid during a fall in temperature.

There is evidence, summarized by Ross,[39] that critical phenomena are not involved in magmatic differentiation, and accordingly that gas-phase reactions are not necessarily to be expected in deep-seated rocks, although he does not question that they are expectable in near-surface volcanism, under lower pressures. Ross has also adduced evidence tending to minimize the potentialities of gas phases in metamorphism, because of their low specific heats and the very low concentrations of the nonvolatile magmatic constituents that, according to the work of Morey, may be expected in them. The argument is a strong one and seems to the writer to place the burden of proof on one who attributes deep-seated metamorphism to gas-phase reactions.

Nevertheless, the existence of gas phases among volcanic phenomena is unquestionable, and their ability to transfer material in large quantities has also been effectively demonstrated by the work of Allen and Zies[40] and Lacroix,[41] while Niggli[42] has brought forth the theoretical reasons advanced above for believing that intrusions at shallow depths will lose a portion of their volatile constituents in the gaseous form. This would also accord with the work of Morey and has been appealed to by Ross[43] as a source of pressure for expulsion of the hydrothermal residue of the magma from the magma chamber. Ross also concludes, however, that such gas phases are, compared to liquid phases, of relatively small importance in the transfer of material. For these reasons the writer believes that although true gas phases are probably developed in the differentiation of an igneous mass at shallow or intermediate depths and that some of the mineral transformations in the Stockton and Fairfield quadrangles are to be attributed to reactions of the country rocks with gas phases, nevertheless the larger part of the metamorphism is probably due to solutions ordinarily called hydrothermal.

TRANSFER OF MATERIAL DURING METAMORPHISM

In describing the metamorphism of the Stockton and Fairfield quadrangles, it has been pointed out that many of the new minerals formed could be easily explained as products of reconstitution of materials already present in the rock. This is "normal" igneous metamorphism and is perhaps exemplified by the less intense metamorphic facies of the Bowman limestone, some parts of the Ophir formation, and parts of the Oquirrh formation at Stockton. To this process is due, for example, the formation of wollastonite in limy sandstone or sandy limestone, of orthoclase and epidote from muscovite-calcite-quartz rocks, and of tremolite and diopside from sandy dolomite or dolomitic sandstone. The work of Winchell[44] on the very similar hornfels of the near-by Bingham district suggests, however, that this process has been almost negligible, most of the silicate minerals being formed from reaction of silica of extraneous source with the carbonates of the limestones.

In addition to the possible reconstitution of materials already present in the rocks in response to the changed temperature and chemical environment in which they were placed by the igneous intrusions, there is unequivocal evidence of great transfer of material. Evidence of the process is present in the ore bodies, in such hornfels masses as those of the Ophir Hill Consolidated mine, and in the jasperoids.

The sulphide ore bodies that have clearly been formed chiefly by replacement of the country rock manifestly represent material added from without. They can not possibly be residual concentrations formed by leaching of a limestone matrix containing scattered sulphides, for there are no evidences of the tremendous loss of volume in the limestone that such a process would entail.

The Ophir Hill Consolidated ore body is well exposed, with its inclosing rocks. The slightly silty limestones of the Ophir formation have been replaced by lime silicate hornfels and finally by sulphide ores on a great scale. The evidence that the replacement was essentially volume for volume (with some slight exceptions to be discussed below) is very good. The limestones can be traced from their essentially unaltered facies directly along the strike into the most altered facies without any appreciable difference in thickness, certainly with no evidence of collapse or mere concentration of impurities. The assumption that there has been essentially no change in volume during metamorphism can not be far wrong. The analyses given on page 104, with the mineral changes therein reflected, show the remarkable chemical transfers that have occurred between the limestones and the magmatic solutions.

For the purpose of this discussion it is unnecessary to refer to the intermediate facies of the limestone but merely to consider the essentially unaltered limestone, No. 1, the most highly silicated rock, No. 4, and the

[39] Ross, C. S., Physico-chemical factors controlling magmatic differentiation and vein formation: Econ. Geology, vol. 23, pp. 869–886, 1928.

[40] Allen, E. T., and Zies, E. G., A chemical study of the fumaroles of the Katmai region: Nat. Geog. Soc. Katmai series, No. 2, 1923. Zies, E. G., The fumarolic action in the Valley of Ten Thousand Smokes: Idem, No. 3, 1924.

[41] Lacroix, A., Étude minéralogique des produits silicates de l'éruption du Vésuve: Mus. hist. nat. Nouv. archives, 4th ser., vol. 9, fasc. 1, 1907.

[42] Niggli, Paul, Die leichtflüchtigen Bestandteile im Magma, p. 52, Leipzig, 1920.

[43] Ross, C. S., op. cit., pp. 879–881.

[44] Winchell, A. N., Petrographic studies of limestone alterations at Bingham: Am. Inst. Min. and Met. Eng. Trans., vol. 70, pp. 888–890, 1924.

sulphide-silicate ore rock, No. 5. The specific-gravity determinations show that the porosity of the unaltered limestone is negligible; that of the hornfels, No. 4, is approximately 0.2 per cent, which is also negligible. There are sporadic vugs in many of the hornstones in the mine, and it is assumed, for the purpose of study of transfers of material, that No. 4 has a porosity of 5 per cent and No. 5, the ore, about 6 per cent. Except for this vug space, the replacement has involved no appreciable change in the volume of the rocks. On these assumptions a comparison of the chemical composition of the three rocks gives a measure of the material transferred during the metamorphism. The following table shows, for Nos. 1, 4, and 5, the weight of each of the constituents determined in the analyses, also the amount of material transferred to or from each rock to produce the next one.

Material transferred to produce ore from unaltered limestone

[Grams in 1,000 cubic centimeters. Figures approximate]

	No. 1	Material transferred to produce No. 4 from No. 1	No. 4	Material transferred to produce No. 5 from No. 4	No. 5	Material transferred to produce No. 5 from No. 1
SiO_2	29	+930	959	−270	690	+660
Al_2O_3	33	+262	295	−20	273	+240
Fe_2O_3	11	+24	35	----------	35	+24
FeO	54	−17	37	+28	65	+10
MgO	119	−70	50	+31	81	−38
CaO	1, 334	−770	564	−475	89	−1, 245
Na_2O	----------	+4	4	+17	21	+21
K_2O	3	+177	181	−48	132	+100
H_2O-	1	----------	2	−2	-------	−1
H_2O+	1	----------	2	+56	58	+57
TiO_2	----------	+13	13	−5	7	+7
CO_2	1, 154	−772	382	−310	71	−1, 082
P_2O_5	1	+6	7	+6	13	+12
Cl	1		1	----------	-------	−1
S	1	+3	4	+24	29	+27
MnO	7	−2	5	+7	13	+5
FeS_2	10	+29	39	+907	946	+936
PbS	----------	----------	----------	+515	515	+515
ZnS	----------	----------	-------	+540	540	+540
Cu	----------	----------	-------	+14	14	+14
F	----------	----------	-------	+9	9	+9
	2, 759	+1, 450 / −1, 600	2, 580	+2, 150 / −1, 150	3, 601	+3, 150 / −2, 350

These figures show that in the metamorphism of the unaltered limestone represented by analysis 1 to the hornfels represented by analysis 4 very remarkable additions of silica, alumina, potassa, and iron sulphide have been made to the rock, with minor additions of soda, titania, and phosphorus. The rock has at the same time lost magnesia and especially lime and carbon dioxide in great quantities. It is not certain that any change in total iron combined as oxide has occurred, though there appears to be a notable oxidation of the ferrous iron to the ferric state, a common feature of contact deposits.[45] The loss of manganese may be insignificant, and it seems that the changes shown in other constituents may be accidental as well.

If it is inferred, as seems probable, that the ore-bearing rock represented by analysis 5 was derived from hornfels represented by analysis 4, there has been a notable loss in silica, alumina, lime, potassa, and carbon dioxide, but a very striking introduction of metallic sulphides and water with smaller additions of soda, magnesia, manganese oxide, phosphorus, and fluorine.

The remarkable total quantities of transferred material are worthy of emphasis. The production of the ore represented by analysis 5 from the relatively unaltered limestones of analysis 1 involves the loss of fully 85 per cent of the materials originally present in the rock and their replacement by the addition of materials whose total weight is greater than the weight of the original rock, the whole having occurred without significant change in the total volume occupied by the rock mass.

The quantitative implications of these figures are perhaps more easily visualized when the ore bodies are compared to the other hornfelses exposed in the mine. According to Mr. H. M. Hartmann, general manager of the Ophir Hill Consolidated mine, fully 1,200,000 tons of ore has been produced from this property. This means roughly 11,000,000 cubic feet of ore. The ore was on the average of somewhat lower grade than the specimen analyzed, but if account is taken of non-commercial stringers it is probable that at least this volume of rock has been altered from a composition roughly that of specimen 1 to that of specimen 5. In addition to this, there must be fully twice as much hornfels, say 20,000,000 cubic feet of composition approximating that of specimen 4, as well as a great deal of less metamorphosed limestones such as are represented by specimens 2 and 3. (See p. 104.) Even if these rocks of lower degree of metamorphism are neglected a simple computation shows that into the area centering in the Ophir Hill Consolidated mine and covering about 3,000,000 square feet, in which the limestones are about 60 feet thick, the following amounts of material at the very least have been introduced:

	Kilograms	Equivalent in tons
SiO_2	900, 000, 000	990, 000
Al_2O_3	270, 000, 000	300, 000
Na_2O	10, 000, 000	11, 000
K_2O	160, 000, 000	176, 000
H_2O+	22, 000, 000	24, 000
TiO_2	11, 000, 000	12, 000
P_2O_5	9, 000, 000	10, 000
S	12, 000, 000	13, 000
FeS_2	380, 000, 000	419, 000
PbS	200, 000, 000	220, 000
ZnS	200, 000, 000	220, 000
Cu	5, 000, 000	5, 500
F	3, 000, 000	3, 300
		2, 403, 800

[45] Butler, B. S., A suggested explanation of the high ferric oxide content of limestone contact zones: Econ. Geology, vol. 18, pp. 398–404, 1923.

The following minimum quantities of material have been removed:

	Kilograms	Equivalent in tons
MgO	64, 000, 000	71, 000
CaO	1, 026, 000, 000	1, 133, 000
CO_2	964, 000, 000	1, 063, 000
		2, 267, 000

The increase in total iron is very great when addition as sulphide is taken into account. The iron combined with oxygen shows no significant change, but there is an advance in the state of oxidation. The carbon dioxide removed is about 10 per cent in excess of the chemical equivalent of lime and magnesia, possibly permitting oxidation of the iron by CO_2 set free through replacement by silica, as suggested by Butler.

Among the most striking changes are those involving the introduction of what are ordinarily considered minor constituents—titania, phosphorus, and fluorine—in great quantities, considering the fact that the estimate above given may be so conservative as to represent less than a quarter of the actual total brought into these areas.

The changes effected by the metamorphosing solutions that produced the hornfels type of alteration and the accompanying sulphide deposits elsewhere in the area were very similar to those at Ophir but were less striking and are less easily susceptible of quantitative estimates. When the total transfer of material is considered the amount must be tremendous.

The transfer of material involved in the jasperoid variety of metamorphism is also very great. Unfortunately, it is not susceptible of anywhere nearly as close quantitative estimation as the transfer involved in the hornfels alteration at Ophir. However, the following analysis of oxidized jasperoid from Mercur shows the marked alteration which has occurred in order to produce this rock from an ordinary limestone.[46]

Analysis of the Sparrowhawk ore

[W. F. Hillebrand, analyst]

SiO_2	81. 70	H_2O-	0. 29
TiO_2	. 20	H_2O+	2. 16
Al_2O_3	3. 24	SO_3	2. 97
Fe_2O_3	5. 41	P_2O_5	. 05
FeO	. 28	Sb_2O_5	1. 02
CaO	. 44	As_2O_5	. 40
BaO	. 43	Mo	Strong trace.
MgO	. 16	Te	Do.
K_2O	1. 10		
Na_2O	. 12		99. 97
Li_2O	Strong trace.		

There has unquestionably been a great loss in total volume of the rock during the change of part of it from limestone to jasperoid, but it seems certain from the field relations that fully 70 per cent of the silica is introduced material. In fact, the assumption that 10 per cent of the silica is residual from the limestone is probably highly excessive. If it is assumed that the total jasperoid in the Mercur district can be represented by a plate 12,000 feet in strike length by 500 feet in dip length by 10 feet in thickness, which seem to be very moderate estimates (see fig. 12), and that 70 per cent of the mass is introduced silica, a total of 34,000,000 tons of silica has been introduced into the limestone in this area. Probably not less than 40,000,000 tons of calcite has been removed from the same area. When the siliceous alteration of the rocks with which the gold ores are associated is also considered, these estimates of material transferred must be admitted to be exceedingly conservative. The fact that only the precipitated material contained in the solutions is available for estimate and that additional material must have been carried off tends to emphasize still further the great volume of material transferred.

COMPOSITION OF METAMORPHOSING SOLUTIONS

The only available clues to the composition of the metamorphosing solutions lie in the effects of the solutions upon the country rock and in the products deposited by them. The substances known from their precipitation to have been present in the solutions include silicon, aluminum, iron, potassium, sodium, water, titanium, phosphorus, sulphur, lead, zinc, copper, fluorine, boron, antimony, arsenic, and barium. From general principles it may be assumed that water was probably the most abundant of these constituents, despite the fact that fully fourteen times as much sulphur, seven times as much potassa, twelve times as much alumina, and forty times as much silica as water have been fixed in the altered rock. The removal of such great amounts of calcite from the country rocks suggests that the solutions were rich in carbon dioxide, a common constituent of volcanic emanations, but this is by no means a necessary condition.

It is obvious that the solutions did not remain purely magmatic after reaching the country rock, for the products of reaction with the country rock must surely have added much material to them. Many other substances may have been present in the solutions but not in sufficient concentration to be precipitated.

Nothing definite is known of the chemical character of the solutions. General theories of magmatic differentiation would suggest that they were alkaline, as they were derived from solutions saturated with alkaline silicates. The great quantities of the very strong base potash which they contained also suggest this character. However, there is some evidence that silica at high temperatures is a much stronger acid former

[46] Spurr, J. E., op. cit., p. 394.

than at low temperatures, and the silica present, together with sulphur and possibly great quantities of carbon dioxide, may have been sufficient to give the solutions an original acid reaction. The limestone would then have acted as a neutralizing agent. The narrowly selective action of the limestones in localizing metamorphism appears, however, to throw doubt on the possibility that the solutions were acid, for if they had been it would seem that one limestone should have brought about neutralization nearly as well as any other. The fact that the solutions crossed considerable thicknesses of limestone by following fractures but not permeating the walls or precipitating any great amount of material, except in one particular bed, suggests that the solutions were not acid.

Other evidence pointing toward an alkaline character of the solutions at the time of sulphide deposition, whatever the character at the time of leaving the magma may have been, is summarized by Spencer.[47]

ZONAL THEORY OF MINERALIZATION

The theory that there is a general zonal arrangement of the metals introduced during mineralization of an area is very attractive, and much evidence tending to support it has been presented. It is too much to say that the facts observed in the Stockton and Fairfield quadrangles are opposed to such a theory, at least in its simplest form, but it is most improbable that the theory would ever have been originated in this area.

Thus copper is usually considered to form in a zone nearer the intrusive mass than lead and zinc. Although the lead-zinc deposits low in copper of the Stockton mining district occur in very close association with igneous masses, copper is much more prominent at the Ophir Hill Consolidated mine than at any other in the quadrangles, yet no igneous rock is exposed there. It is true that the metamorphism in the Ophir Hill mine is of a type generally considered more intense than that common near Stockton, but the association of the richer copper mineralization with the more intense metamorphism seems to the writer a physico-chemical environmental association governed by factors other than mere proximity to a parent magma.

So far as surface exposures are concerned, there is more evidence of close association between the jasperoid alteration in the Mercur-Lion Hill area and igneous rocks than there is between the Ophir Hill silicate-sulphide alteration and igneous rocks. The evidence from innumerable localities about the world however, is overwhelming that the temperature required for the hornfels variety of alteration is notably higher than that ordinarily prevailing during the formation of jasperoid. Despite the presence of some tourmaline in the Mercur jasperoid it must still be considered that the Ophir Hill deposit is a higher-temperature facies than the jasperoid.

To the writer it appears probable that the essential factors governing mineral deposition are temperature, pressure, and concentration and relative solubilities of the different components in the solutions. It is not surprising that a general parallelism should exist in the mineral sequences derived from similar magmas, and that such sequences may be commonly zonal is in accordance with observations made in many parts of the world. However, changes in environment may be occasioned by variations in facility of transfer of solution, by variations in thermal gradients due to fluctuations in igneous activity and variability of country rock, and especially by variations in relative concentration of minerals due to local differences in magmatic evolution. These changes are, it seems, of preponderant effect over mere thermal control governed by spatial relations. In other words, the factors involved in mineralization are such that zoning is to be commonly expected. They are also such as to demand deviations from purely spatial zoning, and the record from many parts of the world, including the area of this survey, seems in accord with this statement.

It seems certain that any zoning which may be present in the mineral deposits is not so well marked that any specific variety of mineralized rock will be found beneath or in a given direction from any other specific variety. The theory can hardly be applied as a guide to prospecting.

WEATHERING

WEATHERING OF THE NONMETAMORPHIC ROCKS

The weathering of the nonmetamorphic rocks of the Stockton and Fairfield quadrangles was not studied in detail. The sandstones disintegrate chiefly by solution of the carbonate cement and by frost action, the quartzites by frost action alone. The limestones generally weather to white, porous, earthy masses, composed chiefly of clay substance, presumably entirely residual. The few shales disintegrate to clayey soils. Both products are so readily eroded that they are found only in sheltered areas.

Igneous rocks respond to weathering by alteration of their feldspars to clay substance and of their mafic constituents to "limonite" and presumably clay and by freeing their quartz. It is probable that some silica, freed by disintegration of the silicates near the surface, is carried below and leads to some silicification, especially of the volcanic rocks.

[47] Spencer, A. C., Geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, pp. 64–68, 1917.

WEATHERING OF THE METAMORPHOSED ROCKS

JASPEROID

Alteration of the jasperoid rocks by meteoric agents results chiefly in mechanical disintegration. However, the sulphide, silicate, and carbonate constituents of the jasperoid are attacked chemically, and the result is a wide diversity of minerals. In fact, several elements found in the oxidized jasperoid have not been recognized in hypogene minerals.

At Mercur orpiment, realgar, and scorodite occur in oxidized jasperoid, but realgar is the only hypogene arsenic mineral observed. The scorodite occurs both in crystalline and colloform masses. Desiccation cracks are evident in the colloform scorodite. The crystalline scorodite is too fine grained for accurate determination, but it clearly has a high birefringence, with all indexes greater than 1.69 and less than 1.72. The colloform variety has an index less than 1.70.

Malachite, azurite, aurichalcite, melaconite, and crysocolla are the copper-bearing minerals of the weathered jasperoid. No hypogene copper mineral was observed in any of the unaltered jasperoid. Similarly, cerargyrite and argentojarosite occur in the weathered jasperoid, though their parent silver mineral was not observed.

The stibnite alters to stibiconite and sulphur, which occupy the space of the parent mineral.

Plumbojarosite is common in the oxidized jasperoid of Lion Hill, and the lead recovered from these ores was probably chiefly present in the form of this mineral. Some of it coats fractures in the jasperoid, and several nodules of the rich horn silver formerly mined in the Chloride Point mine, kindly supplied by George St. Clair, are coated thickly with plumbojarosite. It is probable that this association is merely fortuitous and that there is no genetic relation between the horn silver and the plumbojarosite.

Several potash-bearing clays occur as weathering products of the jasperoid. They resemble kaolinite in mean index but have a much higher birefringence than kaolinite.

Gypsum, calcite as travertine or "onyx marble" and in flat rhombs, and aragonite in long feathery needles are common in the oxidized ore. In a specimen of oxidized jasperoid found on the dump of the Mercur mine at Mercur aragonite needles have grown into vugs in the jasperoid and inclose, toward the center of the vug, radiating crystals of a milk-white mineral which resembles but is not identical with messelite.

Of course, "limonite" is common through all the oxidized jasperoid. Discrimination of the actual mineral composition of this material was not attempted.

LIME SILICATE AND SULPHIDE BODIES

The weathering of the lime silicate and sulphide bodies involves the alteration of the silicates to clays (chiefly potash-bearing), montmorillonite, calcite, quartz, opal, chalcedony, gypsum, and possibly dahllite. The ferromagnesian minerals alter to clays and "limonite." The manganiferous carbonates alter to wad and psilomelane, less commonly to pyrolusite. This is the source of the manganese mined by the Ophir Hill Co. just south of the Canyon fault, north of Ophir.

The alteration of the sulphides is fully as complicated. Pyrite alters to jarosite, "limonite," melanterite, and probably nontronite, as well as to sulphur, locally. Galena alters first to anglesite, then to cerusite where carbonates are in excess in the solutions. However, where the solutions are high in sulphate the alteration proceeds to plumbojarosite. In a few places galena has been attacked by supergene solutions, which have deposited thin films of chalcocite or covellite. Locally the galena alters to pyromorphite, beudantite, or mimetite, as in the gossan zone of the Honerine mine. The arsenic for the beudantite and mimetite is doubtless derived from arsenopyrite, as is that for the rare scorodite.

Sphalerite oxidizes to produce the most diverse minerals of all the sulphides. The oxidized zinc ores of the Hidden Treasure mine, the best example in the district, have been described and their genesis discussed by Loughlin,[48] who summarizes his conclusions in part as follows:

> The principal processes active in the deposition of the zinc and copper carbonate deposits at Ophir may be summarized as follows:
>
> 1. Ferruginous zinc blende was removed by oxidation from mixed sulphide ore bodies, and the resulting zinc sulphate solution migrated downward into the adjacent limestone, which became replaced by smithsonite.
>
> 2. The replacement was accompanied by a considerable shrinkage in volume, expressed by the open lamellar structure of the smithsonite.
>
> 3. The lamellar structure bears a direct relation to fractures or other openings along which the zinc solutions invaded the limestone. The lamellae tend to parallel these openings or to lie concave to the more open parts of fractures. Where the openings were far apart the lamellae present simple forms, but where there was a network of fractures and the permeability of the limestone was not uniform the forms of the lamellae are very complicated.
>
> 4. The expression of shrinkage in lamellae rather than in a honeycomb structure is attributed to a rythmic order of replacement, similar to the process proposed by Liesegang to account for diffusion banding—a process referred to in the last few years by several investigators to account for banded structure in numerous ore bodies.
>
> 5. The contrast between the large amount of shrinkage that accompanied replacement at Ophir and the small amount that took place in other districts studied by the writer is attributed to difference in geologic conditions. In the other districts there is reason to believe that the waters that cause the replacement had already taken in considerable carbon dioxide before replacement of the limestone or related carbonate rock

[48] Loughlin, G. F., Zinc carbonate and related copper carbonate ores at Ophir, Utah: U. S. Geol. Survey Bull. 690, pp. 12–14, 1919.

began and that more zinc carbonate could therefore be deposited than would have resulted from simple reaction between zinc sulphate and carbonate rock; furthermore, that replacement took place near and even below the general or local ground-water level, where the rock could become thoroughly permeated with the zinc solution. At Ophir the opportunity for descending water to obtain carbon dioxide in considerable quantity before depositing zinc carbonate was relatively small, and there is no evidence that downward circulation of the water was impeded at the level of the smithsonite deposits. Such conditions permitted direct molecular reaction between zinc sulphate and limestone, but they were not favorable to replacement volume for volume.

6. A small amount of ferruginous smithsonite was changed under oxidizing conditions into limonite and drusy smithsonite low or lacking in iron. Psilomelane and associated drusy smithsonite had an analogous origin.

7. The scarcity of calamine and zinc-bearing clay at Ophir is attributed to the fact that no volcanic rock formerly overlay the limestone in the vicinity of the zinc carbonate deposits. It is believed that in districts where calamine is abundant the silica of the calamine was derived from the decomposition or alteration of igneous rocks (or other silicate rocks) above the ore horizons. The fact that in the Ophir district calamine is of later origin than both varieties of smithsonite shows that silica does not combine with zinc to form hydrous silicate until the carbon dioxide in solution has been reduced to a very small quantity.

8. Oxidation of chalcopyrite, or cupriferous pyrite, did not take place extensively until after the smithsonite bodies had been formed. The resulting copper sulphate solution migrated downward and doubtless replaced in part smithsonite and in part limestone. The replacement of limestone, which received no special study, was doubtless effected by reactions similar to those involved in the replacement of smithsonite, summarized in the next paragraph. Where replacement was complete copper carbonate ore was formed. This graded downward into smithsonite ore or limestone.

9. Whether smithsonite is replaced by malachite or azurite is thought to depend on the relative amount of carbon dioxide in the sulphate solution. If little is present, replacement by malachite occurs until the carbon dioxide resulting from this reaction is sufficient to cause the deposition of azurite. If much carbon dioxide is originally present in the attacking solution, the smithsonite is replaced at once by azurite, no malachite being formed. Malachite was the principal mineral that replaced smithsonite at Ophir.

10. Where the copper carbonate minerals were deposited in openings carbon dioxide was also the determining factor. Where it was relatively abundant azurite was deposited first, followed, when the supply decreased beyond a certain undetermined point, by malachite. If zinc was present, derived through the replacement of smithsonite, deposition of malachite would continue only until a certain copper-zinc ratio was reached, beyond which the double basic carbonate aurichalcite would be deposited. This ideal order, represented in several of the Ophir specimens, may vary according to variations in the solutions at different times and to other changes in the zone of oxidation.

From the processes of deposition here described it is to be expected that bodies of lamellar zinc carbonate like those of Ophir will prove to be of high grade, owing to the complete removal of limestone, but of small dimensions and confined to the immediate vicinity of fractures and open bedding planes. Such small bodies are not likely to lead to larger bodies of massive ore, unless they lie near to ground-water level or to some impervious stratum or fault that impounded the waters containing the oxidized compounds of zinc.

Owing to the invariable association of minute blebs of chalcopyrite with all the sphalerite of the area, the oxidation products of sphalerite always carry subordinate amounts of copper minerals. Smithsonite (commonly ferruginous), calamine (very common in the Queen of the Hills mine), aurichalcite, hydrozincite, and a zinc-bearing clay are the chief products of the weathering of sphalerite and the attack of the supergene solutions on the underlying rocks. These are commonly accompanied by malachite, azurite, and chrysocolla, derived from the associated chalcopyrite. Some chalcanthite of similar origin occurs in the Ophir Hill and Honerine mines. Sooty chalcocite commonly coats chalcopyrite in small amounts.

MINING HISTORY AND PRODUCTION

The mining history and production of all the districts within the Stockton and Fairfield quadrangles have been carefully summarized up to 1917 by Heikes.[49] The following account is almost wholly quoted from him, with the addition of production data and minor historical details covering the period since 1917.

The Rush Valley and Ophir districts, in Tooele County, were formed June 12, 1864, and August 6, 1870, respectively. These districts were originally part of the West Mountain (Bingham) district. In 1863 they comprised the mining sections now known as Camp Floyd (Mercur), East and Dry Canyon, Tintic, and Tooele districts. A narrow-gage railroad, the Utah & Nevada Railway, was constructed in the seventies from Salt Lake City to Stockton, and in 1905 this was made broad gage and became a part of the Los Angeles & Salt Lake Railroad. In 1912 a branch of this railroad was completed from St. John to Ophir, doing away with a wagon haul of about 16 miles.

RUSH VALLEY (STOCKTON) DISTRICT

Rush Lake, from which Rush Valley takes its name, is a remnant of Lake Bonneville.[50] In 1855 it was included in a military reservation laid out by Lieut. E. J. Steptoe for the purpose of securing to the military post at Camp Floyd the meadow and pasturage about the lake shore. Gilbert says:

"The land surveys in the valley in 1856 did not include the military reservation but showed the existence upon it of a lake. According to Gen. P. E. Connor, who succeeded Colonel Steptoe in 1862, there was then only a small pond, the remainder of the lake bed being occupied by meadowland. In 1865 the water began to increase, the greatest height being attained in 1876 or 1877, since which time it has subsided. The rise of the water submerged the meadowland and rendered the reservation useless for its original purpose. It was therefore officially relinquished by the War Department in 1869. In 1872, the water being near its highest stage, the lake was surveyed in connection with the surrounding country by one of the parties of the Wheeler survey, and the length was de-

[49] Heikes, V. C., in Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 362–370, 382–387, 1920.

[50] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 228, 1890.

termined to be 4¼ miles. In 1880, when the lake was visited by the writer, it was said by residents to have shrunken to half its maximum size."

The reservation[51] for the military post was sold by the Government in 1861 and was repurchased in 1864 by General Conner, who occupied it with a portion of the California and Nevada Volunteers then stationed at Camp Douglas, near Salt Lake. The town of Stockton was surveyed and organized in March, 1864, and made a military post known as Camp Relief.

The Rush Valley deposits were discovered[52] in April, 1864, by some members of Company L, Second Cavalry, California Volunteers, who were guarding stock on the reservation. Assays from the first ledges discovered proved to be rich in silver, and a mining district was organized. The first house was built in Stockton during July, 1864, and in 1866 the town had 40 families and 400 inhabitants.

Soon after the organization of the district Lieut. James Finnerty erected a small trial furnace to test ore, and about the same time a large one was built by the Rush Valley Furnace & Smelting Co. Both were only partly successful owing to the imperfect quality of the fire brick used. Subsequently Lieutenant Finnerty built a second furnace and ran it with good results for a number of weeks, turning out a quantity of metal from surface ore. Attempts to separate the gold and silver from lead by means of the "Lyon process," which was used to smelt the ores of the Perigo mine,[53] in Gilpin County, Colo., were made by the Knickerbocker & Argenta Mining & Smelting Co. but were not successful, and the mines were abandoned in the later part of 1865. The Monheim & Johnson Co.[54] completed a blast furnace in 1866 to treat ores from the Delmonte and Great Basin ledges; J. W. Gibson in the same year erected and put in operation a smelter with a capacity of 600 pounds a day. The Union Vedette says:

"Nine runs have been made of a hundred pounds each, and 300 pounds of metal was obtained, some of which has been brought to this city and assayed by Bohm & Molitor and gives $228 in silver per ton. The remainder is nearly pure lead. * * *."

Soon after the close of the Civil War the volunteers at Camp Douglas were disbanded, being relieved by regular troops from the East. Most of those who had mining prospects, after meeting and amending the by-laws so as to make claims perpetually valid which had but little work done on them, left the Territory to seek employment elsewhere. This action, which prevented all subsequent relocation of the same ground, greatly retarded and in fact prevented for some years the development of the Rush Valley district.[55]

The mining claims of the district center in the foothills 1 to 2 miles due east of Stockton and extend about 2 miles north and a like distance south.

The early conditions of mining, reviewed in brief detail by Sloan[56] in 1873, are of interest. Sloan says in part:

"About midway the district and 1 mile from Stockton is a heavy outcrop of a belt of blue limestone running east and west. Dipping under this is a well-defined vein, 3 feet in width, carrying argentiferous galena, mixed with iron ocher. The following mines are in this belt, which extends about a mile in length. On the east end is the first discovery in the district, called the Lincoln, now known as the Argent; developed by shaft 100 feet in depth and one 50 feet; ore 50 per cent lead and 40 ounces silver to the ton, though one lot yielded 60 per cent lead and 20 ounces silver. * * *

"Adjoining west is the Tucson * * *. One lot of ore yielded 60 per cent lead and 87 ounces silver to the ton.

"The formation is somewhat broken west of the Tucson, but it is evident the Bolivia is on the same vein; it is opened by a shaft over 100 feet in depth, and there is much ore on the dump * * *.

"West from the Bolivia is the Silver King, from which was shipped the first carload of galena ore sent from Utah; * * *. Average of ore in value about 50 per cent lead and 40 ounces silver to the ton.

"Toward the north part of the district is the Southport; quartzite vein carrying galena and carbonates in large quantities; course of vein, north and south; * * * vein about 3 feet in width * * *. The St. Patrick, opened by an incline of 100 feet. This mine at one time yielded a large amount of ore.

"Up Quandary Gulch, one-fourth of a mile from Silver Spring, is the Quandary lode, developed by a shaft over 100 feet in depth, with levels run therefrom.

"Opposite the gulch from the Quandary is the Great Basin lode, opened by tunnel 100 feet and shaft 150 feet; has produced high-grade ore.

"A short distance above the Quandary up the gulch is the first extension north of the Great Central lode, a well-defined, true fissure vein, in quartzite, running north and south; ore about 50 per cent lead and $150 per ton of silver.

"North from the Quandary, on the top of the hill, is the mine Our Fritz, with shaft 100 feet in ore all the way, which assays about 60 per cent lead and $94 in silver to the ton; * * *.

"The First National (formerly Flora Temple) is a well-developed mine with a shaft over 100 feet; strong vein and good body of ore."

Many of these claims, which were worked as individual properties in the early days, now form parts of groups controlled by the Combined Metals, Galena King, and Stockton Lead.

The Great Basin claim, which later became the property of the Honerine, also known as the National, was included in the group of 77 patented mining claims and fractions transferred to the Bullion Coalition Mines Co. in 1910. In 1924 it was taken over, with additional claims, including the New Stockton (formerly the Ben Harrison) by the Combined Metals Reduction Co. At the time of this survey in 1926 and 1927 part of this property was being operated by the company and part by lessees.

The property is opened by an adit 13,000 feet long. The total output of the Honerine and its predecessors is reported[57] to have been 80,000 tons of ore valued at $1,250,000 to the end of 1889. At that time there were 11,500 feet of openings, and the greatest depth was 660 feet. A large concentrator was in operation and has been worked intermittently up to the end of 1913. Between 1890 and 1901 there appears to have been very little ore produced from the Honerine mines; at least, the United States Geological Survey is not in possession of the records.

Since the Honerine property has been operated by the Combined Metals Reduction Co. the milling ores

[51] Union Vedette, published at Camp Douglas, Salt Lake City, Apr. 22, 1864.

[52] Idem, Apr. 2, 1866.

[53] Lyon process and Perigo mines, Colo.: Union Vedette, Jan. 27 and July 18, 1866.

[54] Union Vedette, Apr. 2, 1866.

[55] Whitney's History of Utah, Salt Lake City, Utah, vol. 2, pp. 271–275, 1893.

[56] Sloan, E. L., Salt Lake City Directory, 1874, pp. 148–151.

[57] Jones, M. E., Internal commerce of the United States, p. 892, 1890.

have been treated by selective flotation in the plant at Bauer. Considerable ore is shipped as mined, however.

The Jacobs smelter, built at Stockton in 1872, consisted of three vertical blast furnaces and used ores from the Fourth of July and Kearsarge mines, near Ophir. The Fourth of July was owned by Lilly, Leisenring & Co., of Philadelphia, who were owners of the Jacobs works. In 1879 the Great Basin concentrator, consisting of jigs, was installed in an extension building covering the Jacobs furnaces, and in 1880[58] was milling 100 tons of ore a day, producing 20 tons of concentrate. One stack of the Jacobs smelter was in operation at the same time, reducing about 25 tons of ore a day and turning out about 5½ tons of bullion assaying 100 ounces of silver per ton.

The Chicago smelter,[59] long ago dismantled, was built on the east shore of Rush Lake near Stockton, in August, 1873. Its last operation was recorded in 1880. Huntley[60] says:

"The Chicago smelter is at Slagtown, on the eastern shore of Rush Lake, about 2 miles south of Stockton. It was built in 1873 by the Chicago Silver Mining Co., an English company, which once owned the Chicago and the Queen of the Hills mines, in Dry Canyon. It ran quite steadily until 1877. It was then idle until leased in 1879 to Mr. Brooks, who ran it until the autumn of 1880, when it was shut down."

The Carson & Buzzo smelting works, about half a mile south of the Chicago, erected two vertical blast furnaces in March, 1873, and commenced operations shortly afterwards. The ores used were obtained chiefly from the Utah-Queen mine, owned by the same interests. Later Carson & Buzzo erected extensive reduction works at West Jordan.

The Waterman smelting works were the most important and were operated at a later date (1886) than any in the vicinity. Huntley[61] says:

"The first furnace in the territory, an unsuccessful reverberatory, was erected here in 1864 by General Connor and his officers. It was bought in 1871 or 1872 by Mr. I. S. Waterman. * * * This smelter ran quite steadily for several years on Hidden Treasure ore and some custom rock, but not profitably. * * * During the four years ending April 1, 1878, 26,270 tons of ore were smelted and yielded 8,312 tons of base bullion, which sold for $109.64 per ton, or $911,350. During this time 3,300 tons of flue dust were caught, which assayed from 36 to 57 per cent lead and from 13 to 35 ounces silver."

The production of the Rush Valley district during its early activity is hard to ascertain. No complete records are available, and estimates from the district have been combined with those collected for the Ophir district for the years preceding 1901. The figures in the following table are those given by Heikes up to 1917; for the following years the figures were assembled from the annual volumes of Mineral Resources of the United States, compiled by V. C. Heikes and C. N. Gerry under the United States Geological Survey for 1918–1923, under the United States Bureau of Mines for 1924 and later years.

[58] Rept. Director of Mint upon production of precious metals, 1880, p. 130.

[59] Cameron, J. E., jr., M. E., Mines and furnaces of Ophir, Dry Canyon, and Rush Valley districts: Utah Mining Gazette, June 6, 1874.

[60] Precious metals: Tenth Census U. S., vol. 13, p. 450, 1885.

[61] Precious metals: Tenth Census U. S., vol. 13, p. 450, 1885.

Metals produced in the Rush Valley mining district, 1901–1907

Year	Ore (short tons)	Gold		Silver		Copper		Lead		Recoverable zinc		Total value
		Fine ounces	Value	Fine ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1901	[a] 400	34. 54	$714	6, 618	$3, 971			[a] 200, 000	$8, 600			$13, 285
1902	496	64. 00	1, 323	7, 479	3, 964			250, 651	10, 271			15, 558
1903	142	4. 69	97	1, 211	654			27, 009	1, 134			1, 885
1904	[b] 44, 145	292. 99	6, 056	176, 510	101, 052	5, 248	$656	11, 978, 448	524, 057			631, 821
1905	[b] 40, 431	322. 00	6, 656	56, 025	33, 839	413	65	3, 499, 020	155, 419			195, 979
1906	[b] [c] 37, 409	398. 88	8, 246	95, 861	64, 227	3, 858	745	4, 982, 872	284, 024			357, 242
1907	[b] 48, 318	324. 43	6, 707	130, 487	86, 121	318	63	6, 622, 042	350, 968			443, 859
1908	[b] 2, 602	14. 70	304	31, 386	16, 635	5, 779	763	1, 676, 217	70, 401			88, 103
1909	[b] 5, 627	21. 48	444	24, 096	12, 530	1, 781	232	1, 213, 266	52, 170			65, 376
1910	[b] 1, 981	27. 32	565	15, 888	8, 580	10, 354	1, 315	965, 146	42, 466			52, 926
1911	10, 107	477. 38	9, 868	102, 863	54, 517	12, 689	1, 586	4, 969, 476	223, 626			289, 597
1912	[d] 45, 453	1, 141. 31	23, 593	261, 588	160, 877	319, 859	52, 777	10, 971, 278	493, 708			730, 955
1913	[b] [e] 14, 897	585. 09	12, 094	128, 675	77, 720	29, 521	4, 576	4, 619, 259	203, 247	9, 019	$505	298, 142
1914	19, 332	420. 18	8, 686	108, 979	60, 265	21, 680	2, 883	3, 791, 497	147, 868	69, 582	3, 549	223, 251
1915	19, 780	298. 15	8, 230	90, 666	45, 968	37, 899	6, 633	4, 151, 151	195, 104	99, 034	12, 280	268, 215
1916	24, 710	439. 31	9, 081	108, 841	71, 617	118, 943	29, 260	5, 413, 042	373, 500	136, 615	28, 306	501, 764
1917	10, 713	708. 53	14, 647	79, 797	65, 753	43, 335	11, 830	3, 315, 077	285, 097	56, 490	5, 762	383, 089
1918	8, 031	432. 43	8, 939	78, 247	78, 247	26, 991	6, 667	3, 776, 351	268, 121	23, 089	2, 101	364, 075
1919	4, 913	276. 38	5, 713	50, 033	56, 037	24, 598	4, 575	2, 676, 501	141, 855	70, 698	5, 160	213, 340
1920	3, 103	189. 96	3, 927	26, 978	29, 406	13, 259	2, 440	1, 553, 273	124, 262	25, 143	2, 037	162, 072
1921	1, 731	63. 06	1, 303	16, 357	16, 357	1, 203	155	1, 213, 759	54, 619			72, 434
1922	1, 754	70. 89	1, 465	17, 175	17, 175	3, 962	535	1, 172, 502	64, 488	19, 012	1, 084	84, 747
1923	3, 865	141. 50	2, 925	32, 367	26, 541	14, 758	2, 169	2, 567, 672	179, 737			211, 372
1924	4, 549	172. 91	3, 575	26, 519	17, 768	10, 198	1, 336	1, 851, 687	148, 135	16, 254	1, 063	171, 877
1925	[f] 19, 859	637. 75	13, 184	97, 739	67, 831	90, 459	12, 845	4, 929, 432	428, 861	901, 458	68, 510	591, 231
1926	[g] 36, 584	1, 311. 99	27, 119	174, 667	108, 992	126, 081	17, 651	10, 044, 955	803, 596	1, 962, 198	147, 165	1, 104, 523
1927	66, 573	2, 949. 10	60, 963	271, 325	153, 841	201, 781	26, 433	14, 692, 776	925, 645	3, 634, 134	232, 585	1, 399, 467
	477, 505	11, 920. 95	246, 424	2, 218, 377	1, 440, 485	1, 124, 967	188, 190	113, 124, 359	6, 560, 979	7, 022, 826	500, 107	8, 936, 185

[a] Estimated.
[b] Partly milling ore, concentrates produced.
[c] Mostly old tailings.
[d] Includes 27,647 tons of old slag from early smelting operations.
[e] Includes 2,049 tons of old tailings and slag.
[f] Includes 6,021 tons of milling ore of which 500 tons was old tailings.
[g] Includes 14,787 tons of milling ore.

OPHIR DISTRICT

The ores in the Ophir district were discovered in 1865.[62] Treasure Hill, in East Canyon (now Ophir Canyon), had long been a sacred spot whither the Indians repaired each year to hold councils and to obtain metal for bullets. Soldiers of General Connor's command, attracted by these legends, located a cropping of lead ore at the St. Louis lode, now known as the Hidden Treasure mine. Other locations soon followed, among which were the Pocatello, made near where the Velocipede was afterward located on Silver Shield Hill, and the famous Wild Delirium (now part of the Ophir Hill Consolidated group), at the foot of Ophir Hill.

Very little work was done on the location until 1870, when the excitement caused by the rich developments in the Little Cottonwood district stimulated prospecting. In the summer of 1870 A. W. Moore laid out the town of Ophir, and a new mining district was organized. In August, 1870, horn silver was found on Silverado Hill, perhaps by W. T. Barbee,[63] and the Silveropolis, Chloride Point, Shamrock, and other claims were located. A few days after the discovery of the Silveropolis lode, the Mountain Lion, Silver Chief, Mountain Tiger, Rockwell, and other locations were made on Lion Hill.

The nearest railroad point to Ophir in 1872 was the Utah Southern Railroad, which terminated at Lehi and was reached via Lewiston (near the site of Mercur) and Fairfield. In 1872 the Pioneer mill, belonging to Walker Bros., was treating 25 to 30 tons of ore a day, using a Blake crusher, fifteen 750-pound stamps, an Aikin furnace, six Wheeler pans, and three settlers. There were three smelting plants in the vicinity.[64] Huntley [65] says:

"The Ophir district * * * includes several canyons and ridges on the western slope of the Oquirrh Range, the principal of which are Ophir or East Canyon and Dry Canyon, containing the mining camps of Ophir City and Jacob City, respectively. There was much excitement in 1872, 1873, and 1874, since which time the camp has gradually declined. At the period under review there were not 50 persons where formerly there were 1,000. The records showed about 2,500 locations, on not over 150 of which was assessment work kept up. * * *

"Much of the ore of the district has been very rich, the assays sometimes averaging among the hundreds and even thousands. In East Canyon the ore was usually a very siliceous or milling ore, but that from Dry Canyon contained much lead and was smelted. This district has produced many million dollars—how many can never be known, as the mine owners of the early days are scattered over the Pacific Coast. Many local attempts to treat the ores were made in East Canyon but were for the most part failures. The works remaining at the period under review were the buildings of the Pioneer and the Baltic mills and the Cleveland and the New Jersey arrastres.

"The Pioneer mill was built in 1871 by Walker Bros., of Salt Lake City, to work ore from the Zella group and other mines on Lion Hill. It was a 20-stamp dry-crushing silver mill with an Aiken furnace and cost about $75,000. Many hundred thousand dollars in bullion were extracted. The machinery was moved to Butte, Mont., several years ago. The Baltic mill was a small 5-stamp mill, with two pans and a settler, and was run by a turbine water wheel. It was not worked regularly. The arrastres * * * were fairly successful, owing to the high grade and free nature of the ore. Latterly ore has been shipped to Salt Lake City or to the Stockton smelters. * * *

"The following works were built in early times but had been moved away or were in ruins: Pioneer smelter, built in 1871; probably produced 125 tons of bullion. Ophir smelter, built in 1872; produced but little. Faucett smelter, built in 1872; small product. Brevoort mill, built in 1872; two stamps. Enterprise mill, built in 1873; five stamps. One mill (name unknown), built in 1874; five stamps. Also several small arrastres run by water wheels.

"The Zella group (East Canyon and vicinity) comprises the Zella, Mountain Tiger, Silver Chief, and Rockwell, patented, and several others unpatented. It is situated on the western side and near the summit of Lion Hill. The mines were discovered in the autumn of 1870 and sold to Walker Bros. in 1871, who worked them until 1876, since which time they have been leased. The ore outcropped in two places, the croppings assaying $200 per ton. Three large bodies and several smaller ones were found about 20 feet below the surface. * * * The total product of this group was estimated at $750,000.

"The principal work (on the Monarch group) was done in 1875 and 1876. Since then the property has been leased. * * * It is said that the ore averages 130 ounces silver per ton with from nothing to $8 in gold, and from nothing to 12 per cent of lead. Much of it, however, would assay upward of $500. * * * The total product to the close of the census year was $117,500.

"The Douglas mine was located in 1871 and was worked principally in 1875, 1876, and 1877. It has been idle or leased since. It is situated near the western summit of Lion Hill, about a mile southeast of Ophir City. It is near the Monarch group, which it greatly resembles in gangue and ore. * * * The total product is said to be at least 1,000 tons of 100-ounce ore.

"The Trace group was located in August, 1878, and worked in a small way since by the owners. * * * The total product to the end of the census year was $11,565.

"The other mines of East Canyon and vicinity are:

Mines of East Canyon and vicinity

Mines	Total length of openings (feet)	Total product	Remarks
Exchange and Sunnyside	1,000	$80,000	
Lion	1,000	120,000	
Chloride Point and others on Silveropolis Hill.	----------	----------	Several hundred feet of cuttings; produced many thousands in early days.
Miner's Delight group	[a] 300	----------	Ore assays 19 ounces silver and 11 to 14 per cent lead; sells for $7 per ton; total product, many thousand tons; 1,200 tons extracted in census year.
Bonanza	----------	----------	Has produced considerable ore.
Cleveland Mining Co	1,430	100,000	Ore assays $150 to $1,000 per ton.

[a] Incline; also other cuttings.

[62] Wells, Spicer, Utah Mining Gazette, Jan. 7, 1874.

[63] Huntley, D. B., Precious metals: Tenth Census U. S., vol. 13, p. 477, 1885.

[64] Wheeler, G. M., U. S. Geog. Surveys W. 100th Mer. Prog. Rept., pp. 14–26, 1872.

[65] Op. cit., pp. 450–454.

Mines of East Canyon and vicinity—Continued

Mines	Total length of openings (feet)	Total product	Remarks
San Joaquin	750	$35,000	Ore assays $100 to $400 per ton.
Poorman	[b] 500	Small.	Little ore ever shipped.
Buckhorn	[a] 300		Ore assays 20 ounces silver, 35 per cent lead; much ore formerly produced.
Mountain Gem and Antelope	1,000		Surface ore assays 20 ounces silver, 30 per cent lead; several thousand tons shipped in 1877 and 1878.
California			Ore assays 25 ounces silver, 55 per cent lead.

[a] Incline; also other cuttings.

[b] Drifts; also shaft of several hundred feet.

"The Hidden Treasure mine [Dry Canyon] is situated on a steep hillside above and three-quarters of a mile southeast of Jacob City. It was located in 1865 as the St. Louis lode by General Connor's soldiers, who had been told by Indians of the outcropping boulders of galena. Little work was done until April, 1870, when it was relocated as the Hidden Treasure. The mine has been extensively but irregularly worked since 1872. * * * The ore assays from 15 to 40 ounces silver and 20 to 50 per cent lead. * * * During the four years ending April 1, 1878, 28,400 tons were mined. Most of this was smelted at the Waterman smelter, at Stockton. The cash received for this amount of ore, whether sold as ore or as bullion, was $988,700. Several thousand tons of ore were produced prior to 1874.

"The Chicago mine was located in 1871 and sold to an English company soon afterward. The mine was worked vigorously for several years but has been idle since 1876. * * * The mine produced considerably over 12,000 tons of ore. This company owns the Chicago smelter and when the mine failed bought the Queen of the Hills, Flavilla, and Mahogany locations. They were located in 1870–71 and were worked extensively between 1873 and 1877 but very little since. Shortly after the purchase the Chicago company came to the fault and failed. * * * The product of these mines * * * was probably over $1,000,000.

"The Mono mine is situated half a mile north of Jacob City. It was discovered in the autumn of 1871 and was owned in the early days by Gisborn, Embody, Heaton & Miller. It was worked vigorously by them until 1875, when Gisborn bought the remaining two-thirds interest for $400,000, mortgaging the whole to eastern capitalists for the money. About three months after the sale a fault was found, or the ore shoot 'pinched,' and only a small prospecting force was employed until June, 1879, since which time it has been idle. * * * The total product was not known, even by the original owners, as they divided the proceeds after the sale of each lot. By one it was placed somewhat over and by another somewhat under $1,000,000.

"The Mono tunnel site is in the ravine 800 feet below the Mono mine. Work was begun in 1872 or 1873. The tunnel is about 1,100 feet in length. * * *

"The Kearsarge mine, located half a mile west of Jacob City, was discovered in 1871. * * * The total product was unknown, perhaps $1,000,000. * * * A few hundred tons of 40-ounce ore were produced.

"The Deseret group * * * were located in 1870–71. Work on them was begun in 1874 and discontinued January 1, 1879 * * * The total production of the group was estimated at $30,000.

"The other mines of Dry Canyon are:

Mines of Dry Canyon

Mines	Total length of opening (feet)	Total product	Remarks
Wandering Jew	4,200		A few hundred tons of 30-ounce silver and 35 per cent lead ore extracted.
Utah Queen	900		Large amount of ore extracted.
Sacramento	800		Considerable ore taken out formerly.
Mount Savage and I. X. L.	1,090	[a] 2,100	Ore assays 40 ounces silver and 25 per cent lead.
Emporia	1,600	$30,000	
Fourth of July	[b] 440	[a] 1,000	Ore assays 30 ounces silver and 35 per cent lead.
Evening Star	350		Some good grade ore shipped.
Magnolia			Several hundred feet of incline and drifts; much money spent, little received.
Rattler			Few hundred feet of work done.
Brooklyn			Do.
Elgin			
Noyes			

[a] Tons.

[b] Incline; also other cuttings.

Since 1917, the last year covered by Heikes's summary, the production of both the Rush Valley and Ophir districts has been practically limited to lead-zinc-silver ore and zinc ores, with almost no siliceous or copper ores. The most consistent producers have been the Ophir Hill Consolidated, Bullion Coalition, Hidden Treasure-Cliff, Galena King, Buffalo Consolidated, Cyclone-Tiptop (Stockton Lead Co.) and Ben Harrison. Smaller producers within the decade ending in 1927 include the Kearsarge, Thad Stevens, Mono, Utah Queen, Brooklyn, Surprise Tunnel, Chloride Point, Argent, Twin Magnolia, Lion Hill, Ophir, Northern Light, Queen of the Hills, Three Metals, Jim Fisk,

Lakes of Killarney, Calumet, Lookout, Muerbrook, Southport, Salvation-Hercules, Virginia, and Legal Tender.

The metal production of the Ophir district from the beginning of operations to 1927 is shown in the following table:

Metals produced in Ophir mining district, 1901–1927

Year	Ore (short tons)	Gold		Silver		Copper		Lead		Recoverable zinc		Total value
		Fine ounces	Value	Fine ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1901	[a] 29,600	192.97	$3,989	312,292	$187,375	1,199,476	$200,312	4,357,818	$187,386			$579,062
1902	34,115	164.33	3,397	252,326	133,733	913,622	111,462	3,358,535	137,706			386,298
1903	36,096	182.28	3,768	260,627	140,739	966 291	132,382	2,557,142	107,400			384,289
1904	[b] 37,571	186.02	3,846	240,887	137,908	1,018,577	127,322	2,461,937	107,710			376,786
1905	[b] 39,172	208.00	4,300	265,531	160,381	1,092,784	170,474	3,306,794	164,454			499,609
1906	[b] 40,848	249.00	5,147	257,175	172,307	1,566,831	302,398	7,408,228	422,269			902,121
1907	[b] 50,241	395.20	8,169	335,376	221,348	739,203	147,841	5,913,148	313,397			690,755
1908	[b] 53,002	221.64	4,582	328,606	174,161	1,053,359	139,043	6,000,168	252,007			569,793
1909	[b] 48,354	279.73	5,782	242,340	126,017	736,518	95,747	5,941,455	255,483			483,029
1910	[b] 18,266	230.57	4,767	158,257	85,459	297.253	37,751	6,943,846	305,529			433,506
1911	15.666	242.57	5,014	163,278	86,537	276,640	34,580	4,436,566	199,646	333,876	$19,031	344,808
1912	54,523	276.97	5,725	269,887	165,980	745,525	123,011	6,279,109	282,560	373,870	25,797	603,073
1913	[b] 74,761	236.96	4,898	448,673	270,999	1,462,552	226,695	9,435,529	415,163	769,143	43,072	960,827
1914	76,114	281.14	5,812	432,673	239,268	1,255,335	166,960	8,819,935	343,978	662,785	33,802	789,820
1915	91,572	337.58	6 978	637,643	323,285	2,212,377	387,166	12,232.549	574.930	1,099,138	136,293	1,428,652
1916	94,453	359.99	7,442	724,275	476,573	2,702,165	664,733	12,862,347	887,502	640,251	85,794	2,122,044
1917	80,944	277.92	5,745	538,745	443,926	2,233,687	609,797	9,581,712	824,027	573,528	58,500	1,941.995
1918	[c] 73,444	207.45	4,288	512,702	512,702	1,669,363	412,333	9,135.999	648,656	38,586	3,512	1,581,491
1919	[d] 66,567	260.66	5,388	412,292	461.767	1,290,464	240,026	8,387,451	444,535			1,151,716
1920	[e] 61,119	224.86	4,648	380,077	414,284	1.095,282	201.532	7,637,362	610,989	52,794	4,276	1,235,729
1921	[f] 4,061	69.57	1,438	40,194	40,194	90,895	11,726	960,050	43,202			96,560
1922	[g] 55,218	125.59	2,596	320,470	320,470	767,426	103,602	5,841,343	321,274	17,684	1,008	748,950
1923	[h] 60,585	140.15	2,897	387,528	317,773	943,476	138,691	6,886,989	482,089	96,965	6,594	948,044
1924	[i] 52,998	142.52	2,946	154,755	103,686	387,842	50,807	2,828,812	226,305			383,744
1925	[i] 40,358	305.85	6,322	302,742	210,103	886,271	125,851	5,890,562	512,479	212,159	16,124	870,879
1926	1,437	25.06	518	13,802	8,612	38.553	5,397	434,006	34,721	369,664	27,725	76,973
1927	1,271	26.84	555	10,791	6,119	24,440	3,202	314,019	19,783	392,023	25,090	54 749
	1,292,356	5,851.42	120,957	8,403,944	5,941.706	27,666,207	4,970,841	160,313,411	9,125,180	5,632,466	486,618	20,645,302

[a] Partly estimated
[b] Includes some lead and copper-lead concentrate.
[c] Includes 25,765 tons of shipping ore and 3,921 tons of old tailings.
[d] Includes 21,362 tons of shipping ore and some old tailings.
[e] Includes 17,322 tons of shipping ore.
[f] Includes 1,571 tons of shipping ore.
[g] Includes 590 tons of shipping ore.
[h] Includes 769 tons of shipping ore.
[i] Includes 502 tons of shipping ore and about 8,000 tons of old tailings.
[j] Includes 1,433 tons of shipping ore and 6,351 tons of old tailings.

The combined production of the Ophir and Rush Valley districts from the beginning of operations to 1927 is given in the following table:

Metals produced in Ophir and Rush Valley mining districts, 1870–1927, by periods

Period	Gold		Silver		Copper		Lead		Recoverable zinc		Total value
	Fine ounces	Value	Fine ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1870–1880	12,436.25	$257,080	3,885,938	$4,789,719			77,580,430	$4,335,597			$9,382,396
1881–1890	2,548.99	52,713	1,502,643	1,499,742			10,377,100	447,930			2,000,385
1891–1900	3,411.06	70,513	1,575,538	1,114,951	1,942,682	$253,315	17,358,239	657,364			2,095,143
1901–1910	3,814.77	78,859	3,198,978	1,871,001	9,611,665	1,468,571	79,663,742	3,752,851			7,171,282
1911–1920	7,774.82	160,716	5,556,912	4,095,728	15,592,164	3,190,060	134,045,464	7,688,374	5,033,641	$459,777	15,594,655
1921–1927	6,182.78	127,806	1,866,431	1,415,462	3,587,345	500,400	59,628,564	4,244,934	7,621,651	526,948	6,815,550
	36,168.67	747,687	17,586,440	14,786,603	30,733,856	5,412,346	378,653,539	21,127,050	12,655,292	986,725	43,060,411

CAMP FLOYD (MERCUR) DISTRICT

The history of the Camp Floyd or Mercur district has been summarized to 1917 by Heikes, and no activity has been reported in the district since his summary was written.

The Camp Floyd district is about 55 miles south of Salt Lake City, in Tooele County, adjoining the Ophir mining district. It contains three distinct camps—Mercur, the most important, in Lewiston Canyon; Sunshine, about 4 miles south of Mercur in Sunshine Canyon; and West Dip (on the west dip of the anticline), about 2 miles west of Mercur near the western part of the range. The Salt Lake & Mercur Railroad, which was dismantled in 1914, connected with the Los Angeles & Salt Lake Railroad at Fairfield junction and furnished transportation for the district. The district was first organized at the beginning of a silver excitement on April 16, 1870,

and later was practically abandoned until the discovery of gold ore, which was successfully treated by cyanidation in 1891. On June 24, 1894, it was reorganized.

The early history of the district is reviewed by Huntley,[66] who says:

"The Camp Floyd district is south of the Ophir district and is on the same range. It is an irregular rectangle, from 7 to 9 miles on a side, the mines themselves, however, being included within an area of a square mile. * * * The Carrie Steele mine * * * was discovered in 1873 by Leandro Steele; was worked from 1876 to July, 1879, when it was sold to the Carrie Steele Mining Co., of New York. * * * One large body of antimonial ore 20 feet thick and 60 by 70 feet in extreme width and length was found at the surface. The richest ore averaged $700 and occurred in a seam from 8 to 10 inches wide next to the roof. * * * The mill * * * was built by an English company in 1872–73 to work the ores of the Sparrowhawk mine. * * * It was purchased by the Carrie Steele Mining Co. in 1879 and ran from May 10 to August 15, 1880. * * *

"The other mines of the Camp Floyd district are:

Mines of Camp Floyd

Mines	Total length of openings (feet)	Total product	Remarks
Sparrow Hawk	6,000	$300,000	Ore similar to that of Carrie Steele.
Star of the West	500	None.	No ore shipped.
Silver Circle	1,000	Small.	In 1873 many thousand dollars spent in prospecting.
Silver Cloud	800	----------	Formerly shipped a few hundred tons of $30 ore.
Mormon Chief	1,000	----------	Little done since 1875.
Elkhorn	500	50,000	

The production of the district from 1871 to 1881 is estimated by Spurr[67] at 46,000 ounces of silver; the ores then worked contained no lead, copper, nor gold. The gold production of the Camp Floyd district, which became important in 1892, amounted in that and the succeeding year to about 19,000 ounces.

Gemmell[68] gives the following history of the district up to 1897:

"When the district was organized on April 16, 1870, it naturally was called the Camp Floyd mining district. The first location in the district was a placer claim, located by L. Greeley on April 20, 1870. Other and similar locations followed, but placer diggings could not possibly be made to pay, for two very good reasons—lack of gold that could be panned and lack of water. The Sparrow Hawk, Last Chance, and Marion claims were among the first lode claims located. Some very rich silver ore was discovered on them (some of it going $4,000 or $5,000 to the ton), and they were soon sold to an English syndicate. The ore proved to be very 'pockety,' and after building a mill, spending about $700,000 and clearing only about $100,000, the company suspended operations.

"Soon after the Sparrow Hawk discovery a rich strike was made in the Carrie Steele. It is said that from this pocket a few men took out about $83,000 in three months. Other strikes followed, and in 1872 and 1873 the hills were swarming with prospectors. The town of Lewiston was built on the present site of Mercur and was soon a full-fledged mining camp. * * * But no steady producing mines were found; the excitement began to die away, and Lewiston, which had grown to a town of some 1,500 people by 1880, had dwindled down to one house and to one inhabitant, Moses Manning, who remained to work out his own and others' assessments. It is estimated that during this excitement about $350,000 were taken out and that many times that amount was expended. Machinery, supplies, and labor were all so high that it required $60 ore to pay.

"On April 30, 1879, a German named Arie Pinedo located the Mercur lode, believing he had discovered a valuable vein of cinnabar and naming the claim after the German word for mercury—Mercur. Some cinnabar was found, but not in paying quantities, and Pinedo soon abandoned the claim and left the country. Other prospectors drifted in, and about 1883 the gold ledge was discovered. The assay returns showed the yellow metal to be present in paying quantities, but after numerous attempts at panning with never a color, the prospectors gave it up.

"In March, 1889, Capt. Joseph Smith * * * put up a mill on the Marion ground for the purpose of working the silver ore and tailing dump. * * * After spending $9,000 or $10,000 with no substantial result, Captain Smith was forced to abandon the idea of making the silver ores pay. He remembered the stories of cinnabar and gold being found in the Mercur ore, sampled the vein in the summer of 1889, and got good returns in gold. All thought of mining for silver or cinnabar vanished, and during the winter of 1889–90 some work was done on the Mercur lode. A 5-ton lot of the ore was brought across the canyon to the Marion mill and treated with apparent success.

"Messrs. G. S. Peyton and H. W. Brown associated themselves with Captain Smith in March, 1890, and incorporated the Mercur Gold Mining & Milling Co. * * * Twenty-five thousand dollars were spent under the direction of Captain Smith in building a mill near a spring at what is now called Manning, about halfway between Mercur and Fairfield station. This was an amalgamating mill, like the one previously built on the Marion ground. * * * Five thousand dollars were spent in developing the mine and fixing up the wagon road from the mine to the mill. The attempt to treat the ore by amalgamation proved a failure, however, and once again the hopes of getting any money out of the ores of Camp Floyd district were blasted. About 1,500 tons were put through the mill that by careful sampling had averaged about $18 per ton. Assays of the tailings showed an extraction of about 80 per cent, but the clean-up, instead of amounting to about $21,000, proved to be less than $5,000. Cyanide of potassium had been used for cleaning the quicksilver, and subsequent experiments proved that the gold had been dissolved and carried off by the cyanide.

"About this time the successful treatment of gold ores by the cyanide process became generally known, and * * * a carload of ore was shipped to Denver for a practical test. An extraction of about 80 per cent was obtained by this test, and in the summer of 1890 the mill at Manning was remodeled and turned into a cyanide plant, by which the ore was successfully treated. Captain Smith, having severed his connection with the Mercur mine, turned his attention to the development of the gold ledge in the Marion group of claims. He remodeled and added to the amalgamating mill previously built, and by June, 1893, started up the second cyanide plant in Mercur."

The successful treatment of the gold ores being assured, prospectors again swarmed in. Arthur Murphy and C. L. Preble

[66] Tenth Census U. S., vol. 13, pp. 454–455, 1885.

[67] Spurr, J. E., Economic geology of the Mercur mining district: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 355, 1895.

[68] Gemmell, R. C., Eng. and Min. Jour., April 24, 1897.

located two claims on the old site of Lewiston, staked them out into town lots, and saw a new town (Mercur) grow to be about the same size as Lewiston in its palmy days—about 1,500 inhabitants. By 1897 Mercur had become a regularly organized municipality, with a water system and fire department. In 1900 the population reached 2,351, but dwindled in the next decade to 1,047 inhabitants, and in 1913 [the town] was almost entirely abandoned on the closing of operations by the Consolidated Mercur Mines Co.

The following table shows the metal output from the Camp Floyd district from the beginning of operations to the close of 1917:

Metals produced in Camp Floyd district, by period[a]

[No production has been made since 1917]

Period	Ore (short tons)	Gold		Silver		Total gross value recovered
		Fine ounces	Value	Fine ounces	Value	
1871–1881[b]				46,000	$55,936	$55,936
1890–1900	1,929,993	382,790.00	$7,912,973			[c] 7,912,973
1901–1927	3,653,990	538,052.87	11,122,539	2,760	1,576	[d] 11,124,115
	5,583,983	920,842.87	19,035,512	48,760	57,512	19,093,024

[a] From 1903 to 1907, 3,338 flasks of quicksilver were produced from the Sacramento mine.
[b] Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey, Sixteenth Ann. Rept., pt. 2, p. 354, 1895.
[c] Average recovery, $4.10 per ton.
[d] Average recovery, $3.04 per ton.

From 1890 to the close of 1917 there were produced in the Camp Floyd district by the Mercur, Delamar, Geyser-Marion, Sacramento, Sunshine, Overland, Daisy, and La Cigale properties 5,583,513 tons of ore valued at $19,034,984. All had mills, and all except the La Cigale were successful in extracting fair values from the ores. The first five properties paid $3,881,323 in dividends to stockholders—the total amount paid during the greatest activity in the district. The old Mercur Gold Mining & Milling Co. paid dividends of $1,481,000, and the Delamar Mercur Mines Co. dividends of $689,812.99 to August 1, 1900.[69] These two companies[70] had mined up to that time 1,045,136 tons of ore at a profit of $2,181,401, or about $2.09 per ton. From August 1, 1900, to 1913, inclusive, the Consolidated Mercur Mines Co. produced gold in precipitates and bullion valued at $10,549,377, recovered from 3,291,485 tons of ore (including some tailings), or an average recovery value of $3.20 per ton of material treated at a total cost of $2.82 per ton.[71] Dividends paid aggregated $1,374,500 to July 31, 1913. The Mercur & Brickyard-Golden Gate (Delamar) property yielded 4,336,621 tons of ore, from which $16,419,541 was recovered, an average of $3 78 per ton. Dividends paid during the life of the combined properties amounted to $3,445,312.

After the first test was made on Marion and Mercur gold ore by amalgamation at the Marion mill in Lewiston Canyon, the mill erected at Manning, in Fairfield Canyon, for the treatment of the ore in 1890 was similarly equipped, using pan amalgamation.

In a personal communication[72] G. S. Peyton, discoverer of the process that made Mercur famous, gives the early history of the Mercur mill as follows:

"The Mercur mill was built under the advice and supervision of Joseph Smith, superintendent, at Manning in the years 1890–91 by the Mercur Gold Mining Co., organized in May, 1890. * * * The amount of gold first saved by this process of amalgamation was $3,000, representing about 15 per cent of the value of the ore. In July, 1891, a car of the $17 ore was shipped to Denver for trial by the cyanide process, which successfully extracted 92 per cent of the values. The amalgamation equipment and concentrators were then discarded, and the cyanide plant completed and started in February, 1892, on ore averaging $12 per ton in gold, of which 86 per cent was saved."

As experience was gained in the handling of the ores by the new cyanide process the mill was enlarged. * * * In 1896 the mill was treating 225 tons of ore daily, or altogether 63,480 tons for the year, averaging in value about $12 per ton in gold, of which about 80 per cent was saved. The average cost of mining and milling was about $2.80 per ton. The total amount paid in dividends up to January 1, 1897, was $600,000.

During 1897 and 1898 the Golden Gate mill was built at Mercur, and in 1900 the Delamar-Mercur Mines Co. and the Mercur Gold Mining & Milling Co. were combined and thereafter called the Consolidated Mercur Mines Co. All of the ore from the Mercur and Delamar mines was afterwards treated in the Golden Gate mill, the Manning mill being used intermittently by the company and lessees for the re-treatment of tailings. The original capacity of the Golden Gate mill was 500 tons but by 1900 it was increased to 1,000 tons of ore daily.[73]

A summary of the production and costs of operations is given in the table on page 125.

The character of the oxidized and base ores of the Golden Gate claims in the Camp Floyd district are discussed by D. C. Jackling,[74] who says:

"Locally, the ores are classified into three varieties, according to their mode of treatment:

"First, 'oxidized ores,' consisting of a mixture in which the calcareous and siliceous varieties predominate and in which the proportion of clay and talc is insufficient to interfere with percolation. This class of ore contains only an insignificant quantity of compounds of base elements, showing only very small fractional percentages of mercury, as cinnabar and arsenic oxidized compounds.

"Second, 'talcy ores,' which are almost entirely clay and talc and soft, decomposed porphyry. These ores, like the class

[69] Consolidated Mercur Gold Mines Co.'s annual report for the year ending June 30, 1901.
[70] Idem, p. 13.
[71] Howard, L. O., and Maguire, D., Cyanidation in the Mercur district of Utah: Pamphlet published by Salt Lake Min. Rev., p. 20, 1913.
[72] Letter from G. S. Peyton to V. C. Heikes, dated November 23, 1914. Mr. Peyton was then living at Rackerby, Calif.
[73] For a full description of the original plant on the Delamar property see Director of Mint Rept. upon production of precious metals for 1899, pp. 181–187, 1900.
[74] Director of Mint Rept. on production of precious metals for 1899, pp. 181–182, 1900.

Summary [a] of classified ores and tailings treated at the Consolidated Mercur Mines Co.'s mill, 1901–1912 (from company reports)

Production

Year ending June 30—	Gross production	Other income	Tons base ore	Tons oxidized ore	Total tons	Average daily tonnage	Recovery	Tailings loss	Value per ton	Mining cost	Milling cost	Total cost	Profit per ton	Dividends		Per cent extraction
														Amount	Per cent of gross	
1901 [b]	$1,493,993.80				288,295	875	$5.19	$0.95	$6.14			$3.18	$2.01	$235,000	15.73	82.8
1902	1,457,064.47	$1,712.50			321,626	895	4.53	1.19	5.72	$1.41	$2.09	3.50	1.03	465,000	31.91	79.2
1903	1,321,009.63	9,277.50			335,163	931	3.84	1.21	5.05	1.30	1.58	2.88	.96	330,000	24.98	76.0
1904	648,516.48	8,432.68			266,701	630	2.86	1.03	3.89	1.40	1.60	3.00	.04			73.5
1905	742,291.76	12,385.15	79,703	165,323	245,026	671	2.97	.985	3.95	1.51	1.12	2.63	.34	25,000	3.37	75.3
1906	870,887.14	9,494.77	126,538	176,268	302,806	830	2.80	.956	3.76	1.41	1.07	2.48	.32	100,000	11.48	74.5
1907	642,843.90	14,445.10	110,069	135,100	245,169	672	2.62	.98	3.60	1.45	1.18	2.63	.01	50,000	7.78	72.8
1908	644,353.91	15,587.25	87,492	138,737	226,229	625	2.85	.92	3.77	1.65	1.26	2.91	.06			75.6
1909	761,235.66	13,182.10	107,607	175,262	282,269	773	2.70	.88	3.58	1.53	1.09	2.62	.08			75.4
1910	613,148.92	12,741.12	99,447	132,190	231,631	638	2.65	.94	3.59	1.48	1.15	2.63	.02			73.8
1911	550,695.70	7,933.49	78,897	131,622	[c] 239,190	659	2.32	.88	3.20	1.29	1.04	2.33	.01			72.3
1912	[d] 494,133.65	3,970.98	67,816	119,776	[e] 201,652	560	2.45	.82	3.27	1.32	1.10	2.42	.03	30,000	6.01	74.9
	[f] 10,240,175.02	109,162.64			3,145,757	731	3.26	.99	4.255	[f] 1.43	[f] 1.33	2.82	.455	1,235,000	12.54	76.7

Material treated

	1909	1910	1911	1912		1909	1910	1911	1912
Oxide ore teated—tons	175,262	132,190	131,622	119,776	Ore and tails leached—per cent			76.4	75.5
Base ore treated—do	107,607	99,447	78,897	67,816	Oxidized classified—do	64.7	60.9	86.0	79.4
Slime plant:					Base classified—do	.0	41.9	90.2	94.8
Sand—do	34,470	82,763	128,031	110,126	Total ore classified—do	21.9	52.7	87.6	85.0
Oxidized—do	34,470	51,532	74,600	61,854	Ore and tails classified—do			77.1	79.0
Base—do		31,231	53,431	48,172	Oxidized filtered—do	15.7	21.9	29.3	27.7
Slime—do	27,523	39,362	56,482	49,377	Base filtered—do	.0	10.5	22.6	23.8
Oxidized—do	27,523	28,953	38,621	33,243	Total ore filtered—do	9.8	17.0	26.8	26.3
Base—do		10,409	17,861	16,134	Ore and tails filtered—do			23.6	24.5
Oxidized leached—per cent	84.3	78.1	70.7	72.3	In sand tails—cents per ton	72	84	84	
Base leached—do	100.0	89.5	77.4	76.2	In slime tails—do	54	83	100	
Total ore leached—do	90.2	83.0	73.2	73.7					-

[a] Cyanidation in the Mecur district, Utah, pamphlet published by Salt Lake Min. Rev., 1913.
[b] For 11 months.
[c] Includes 28,671 tons of tailings.
[d] Corrected figures from company report.
[e] Includes 14,060 tons of tailings.
[f] For 11 years.

above, are almost free from base-element compounds but impossible of percolation, for the reason that on contact with water they disintegrate and settle to an almost impervious mass.

"Third, 'base ores,' consisting of a mixture of the above classes, with the calcareous and talcose varieties predominating, and containing large quantities of base-metal sulphides. Arsenic is the chief of these, occurring as realgar, orpiment, and mispickel, in quantities sometimes as high as 50 per cent but averaging not to exceed 2 per cent. Realgar is by far the most plentiful of the arsenic-bearing minerals, fully three-fourths of the arsenic appearing in this way. Antimony is present as stibnite. Occasional small quantities of galena occur.

"Considerable quantities of iron pyrites are frequently encountered in minute crystals. Mercury is invariably present but in less quantities than in the oxidized ores. Various hydrous sulphates of iron are present, as well as oxidization products of arsenic, both simple and in combination with lime and magnesia. Some of the rare elements, most notably tellurium, are also present, in traces only. The clays of this class of ore are invariably dark gray or black in color, due to a considerable quantity of carbon, frequently as much as 4 per cent, and in these are sometimes found organic compounds which decompose potassium cyanide very rapidly. Silver is very sparingly distributed in all classes of ore, rarely exceeding 1 ounce of silver to 10 ounces of gold. No metallic gold is visible in any of the ores until after they have been roasted, when occasional minute, irregular particles may be discovered under the microscope. All the clean, base minerals are invariably poorer in gold than the gangue with which they are associated. The clear crystals of realgar and orpiment carry none at all, or only traces, showing that the increased values of the base ore are not directly due to these base-metal minerals. The gold in whatever ore found dissolves very rapidly and completely in solutions of potassium cyanide, indicating that it is very finely divided in whatever condition it occurs, and these various facts have led me to the conclusion that the gold in these ores is present in a finely divided amorphous metallic state, having the black or brown color characteristic of the metal when in this condition, and consequently being unrecognizable under the microscope in its naturally occurring state."

The Marion was the first mill to be built in the Mercur area. It was part of the old Sparrow Hawk works erected for the treatment of silver ores in 1872–73, operated again on silver ores in 1880, and again, for the last time in March, 1889, when it treated 12 tons of ore daily by pan amalgamation with poor success. In 1893 it was changed to a cyanide plant, the second in the district, and was equipped for a capacity of about 50 tons of ore daily.

In 1893 the Camp Floyd district produced between 14,000 and 15,000 ounces of gold from the Mercur and Marion mines. The scarcity of water was a decided obstacle to milling in Lewiston Canyon until a pipe line was run from the Ophir district in 1893. Ore from the Marion was crushed to a size that would pass through a ⅞-inch mesh screen. The average cost of mining and milling was said to be about $2 per ton.

The next summer (1894) the Geyser Co., whose claim adjoins the Marion, commenced work on a cyanide plant with a capacity of about 100 tons of ore daily but finished it too late in the year to permit much production. The ore took 90 hours to leach, as it was not put through screens but was simply crushed in a Gates gyratory crusher. The amount of cyanide consumed was about three-eighths of a pound per ton of ore treated, and the cost of mining and milling was said to be about $1.60 per ton.

In 1897 the Geyser-Marion interests were combined, and the Marion equipment added to the Geyser mill. The yield in gold from this property was reported to be $120,000 in 1899. The property was last operated under its old name in 1900. It was sold at sheriff's sale shortly after and worked with little success by a new company until put into the hands of a lessee, who barely succeeded in making the property pay expenses. The dividend record shows nearly $100,000 was paid to stockholders, and it is estimated that close to $500,000 in gold was recovered between 1893 and 1913.

A fourth cyanide plant was built on the Sacramento property in 1895. Success was poor at first, owing to the baseness of the ores, and thereafter only oxidized material was handled. Roasting furnaces were added to an enlarged mill in 1901 and slime tanks the following year. The ore treated at the mill averaged $4.60 in gold per ton in the beginning and as low as $3 per ton at the end of operations in 1907. The costs of mining and milling are said to have been about $1.50 per ton, and the loss in the tailings averaged about $1 per ton. The total value of the gold recovered during the life of the mine is estimated at $1,500,000, and $308,000 was paid in dividends. In addition, the Sacramento mine was for several years the most important producer of mercury in Utah.

A few years after the first gold discoveries were made in the Camp Floyd district the Sunshine and Overland mills were built at Sunshine, 4 miles south of Mercur, to treat gold ores similar to those of Mercur. The Sunshine property was the first to be equipped with a cyanide mill, which operated from December, 1895, until October, 1896, milling about 9,000 tons of $3 to $4 gold ore and obtaining about $7,000 in gold at the expenditure of several times as much. In 1898–99, according to Charles Butters,[75] another unsuccessful effort was made to treat the ore. In 1902 the mill was again started but was closed at the end of the year after producing about $70,000 in gold bullion. In 1908 the mill was overhauled by the Boston Sunshine Gold Mining Co., which treated 125 to 150 tons of ore daily, beginning in May, 1909. By July, 1910, the ore supply of the Sunshine mine was exhausted after slightly over 50,000 tons had been treated with an average recovery of $2.81, or a total of $141,532, extracted at a milling cost, it is reported,[76] of 88 cents per ton, with only 20 to 40 cents left in the tailings. Dividends from these last operations aggregated $27,261. In all the Sunshine mine is believed to have yielded about $221,000 in gold.

The Overland Co. erected the second mill in the camp, starting operations in November, 1898, on ore from its property. It was the first mill in the district to use electric power. Development in the upper levels of the mine was by an incline shaft and in the lower by a vertical shaft that cut the ore bed at 1,600 feet on the dip. The first ores treated ranged from $6 to $8 per ton in gold but decreased to about $2.30 a ton at the last, yielding all but 40 cents of its gold, which remained in the tailings. The mill was closed for alterations in 1899 and was started again in 1901, having been enlarged to treat 500 tons of ore daily. It is reported that the cost of mining was 85 cents and milling 25 cents per ton. The last work on the property was done under a receiver in 1904–5. No dividends were ever reported, although the property had a record of producing $219,646 in gold from about 156,000 tons of ore.

West Dip [West Mercur] is 4½ miles northwest of Mercur and was so named from the fact that the rocks at that point dip about 45° W., in contrast with the east dip in the Mercur camp, on the opposite side of the anticline.

[75] Personal communication.

[76] Cyanidation in the Mercur district of Utah, pamphlet published by the Salt Lake Min. Rev., 1913.

Mining began in 1897, and in July, 1898, the Daisy mill, with a capacity of 112 tons a day, was erected. It is said to have produced $75,000 in gold precipitates up to the end of 1899. In July, 1900, the Daisy mine and mill went into the hands of a receiver. The Daisy property is opened by an incline shaft to the 700-foot level and had ore assaying from $4 to $8 per ton. The total cost of mining and milling amounted to $3 per ton. Equipped about 1910 with modern machinery consisting of classifiers, mixers, and filter presses, the mill was the first to make a success of the West Dip ores. It was completely destroyed by fire in 1917.

In December, 1898, a mill was started on the La Cigale property, which is developed by several shafts, the deepest in 1897 being 410 feet sunk on an incline of 45°. The ore is difficult to treat, and at the end of 1899 work was abandoned. No other attempts have been reported.

MINERALOGY

The minerals that have been reported from this area or recognized in the course of this survey are listed below in accordance with the classification of Dana, with brief notes as to their occurrence.

NATIVE ELEMENTS

Native gold has never been observed in any of the ores, either of Mercur, primarily a gold camp, or of any of the other mining districts. It is known only from assays.

Native silver was not seen during this survey but is reported to have occurred in small quantity in the oxidized ore of the Jim Fisk mine, in Ophir Canyon.

Native sulphur occurs as a product of oxidation of metallic sulphides at Sunshine, in the jasperoid of Lion Hill, and at the Mayflower mine.

Carbon, in some form, impregnates some of the quartz of the Mercur jasperoid and probably is a minor constituent of some of the Ophir hornfels.

SULPHIDES AND ARSENIDES

Realgar (AsS) occurs at Mercur in massive replacement deposits in limestone and disseminated in jasperoid.

Orpiment (As_2S_3) occurs in the Mercur district, both in limestone and disseminated in the jasperoid, probably chiefly as an oxidation product of realgar.

Stibnite (Sb_2S_3) is present as needlelike crystals replacing quartz in the jasperoid at Mercur and Lion Hill.

Galena (PbS) occurs in all the mines at Ophir, Dry Canyon, and Stockton and in the Mayflower mine, in West Canyon. It is both massive and intermixed with silicates and other sulphides. Some galena from vugs in the Ophir Hill mine has large octahedral faces almost to the exclusion of the common cube form.

Argentite (Ag_2S) was observed only in microscopic blebs in galena from all the mines where galena is found.

Chalcocite (Cu_2S) forms sooty coatings on chalcopyrite along the Cliff fault in the Ophir Hill Consolidated mine.

Sphalerite (ZnS) is the common hypogene zinc mineral and is present in all the sulphide mines from Lion Hill to the Stockton district. It also occurs locally as a "contact" mineral in the hornfels of the Soldier Canyon stock.

Cinnabar (HgS) is disseminated in the altered limestones at Mercur. It was found in commercial quantities only in the Sacramento mine.

Covellite (CuS) occurs in the Kearsarge mine and probably in a few other localities as a supergene sulphide, replacing chalcopyrite.

Wurtzite (ZnS) the hexagonal zinc sulphide, was found in barrel-shaped crystals as much as 2 millimeters long coating chalcopyrite in vugs in the Ophir Hill mine. No evidence was discovered bearing on the question of hypogene or supergene origin.

Pyrrhotite (Fe_nS_{n+1}) occurs in the Ophir Hill Consolidated mine, impregnating both the hornfels and filling fissures. It is also present sporadically in the Settlement Canyon contact rocks.

Bornite (Cu_5FeS_4) is rare, occurring only as a supergene mineral along the Cliff fault in the Ophir Hill mine.

Chalcopyrite ($CuFeS_2$) is the common hypogene copper mineral. It was found in the Lion Hill jasperoid, in the Ophir Canyon, Dry Canyon, and Stockton mines, replacing hornfels and limestone.

Pyrite (FeS_2) is the most abundant and widespread sulphide in the region. It occurs in all the mineralized areas and as sporadic crystals in hornfels, rhyolite, and monzonite, remote from other sulphides.

Arsenopyrite (FeAsS) was found in small amounts in the Honerine and Ben Harrison mines.

SULPHARSENITES AND SULPHANTIMONITES

Boulangerite ($5PbS.2Sb_2S_3$) occurs in considerable quantity at the Mayflower mine, in West Canyon. It was identified by M. N. Short.

Tetrahedrite ($4Cu_2S.Sb_2S_3$) was reported by Butler as an uncommon mineral in the Honerine mine. It was not found during this survey.

Tennantite ($4Cu_2S.As_2S_3$), the arsenic analogue of tetrahedrite, was found in the Ophir Hill Consolidated mine both as a vein mineral and as massive deposits replacing hornfels. Qualitative tests by M. N. Short showed a very low content of isomorphous tetrahedrite.

HALOIDS

Cerargyrite (AgCl), horn silver, forms waxy masses in the mines of Lion Hill. It is confined to the zone of oxidation, in which it was very richly concentrated. Most of it has long since been mined.

Fluorite (CaF_2) is a hypogene mineral in the mines of Lion Hill, Ophir, Dry Canyon, and Stockton. It is widespread but not abundant. It also occurs in small quantities in some of the contact zones in Soldier and Settlement Canyons and the Stockton district.

OXIDES

Quartz (SiO_2) is the dominant mineral in the many quartzite beds, as well as in most of the igneous rocks and in the jasperoid and hornfels associated with the ore deposits.

Chalcedony (SiO_2), a fibrous modification of silica, occurs in the jasperoids and in the oxidized parts of some of the ore bodies as a very subordinate mineral.

Tridymite (SiO_2), a hexagonal modification of silica, is doubtfully present in some of the volcanic rocks in the Fairfield quadrangle, as microscopic rosettes in amygdules.

Opal ($SiO_2.nH_2O$) occurs as a supergene mineral in some of the ore bodies and in some of the lavas.

Stibiconite ($H_2Sb_2O_5$) forms an oxidation product of stibnite in the jasperoids of Lion Hill and Mercur. It is uncommon.

Cuprite (Cu_2O) is present in minute amounts in the oxidized ores of Dry Canyon.

Melaconite (CuO), the black, earthy variety of tenorite, is a rare mineral of the oxidation zone in the Lion Hill jasperoid.

Hematite (Fe_2O_3) was identified in the contact zone of the Soldier Creek stock as crystals of the specularite variety, as much as 0.5 millimeter in size. It probably also occurs, though not identified, in the gossan zones of some of the ore bodies.

Magnetite (Fe_3O_4) is an accessory constituent of most of the igneous rocks of the quadrangles, but was not identified elsewhere.

Rutile (TiO_2) is an accessory constituent of many of the igneous rocks of the area. It is also present in minor quantities in the Mercur jasperoid and in the Ophir Hill hornfels.

Pyrolusite (MnO_2) occurs along the Cliff fault in the Cliff mine, in the limestone mass south of the Canyon fault north of Ophir, and elsewhere, as a film on quartzite. It is an oxidation product.

Goethite ($Fe_2O_3.H_2O$) is probably the commonest constituent of the gossan of the ore deposits. No distinction was attempted between this mineral, lepidocrocite, and amorphous "limonite." All are grouped together in this report as "limonite."

Psilomelane, a hydrous manganese manganate, occurs as an oxidation product of manganiferous calcite and dolomite at Ophir and Stockton.

Wad, a mineral resembling impure psilomelane, is very common in small amounts in the oxidized zone of the ore deposits.

CARBONATES

Calcite ($CaCO_3$) occurs in the limestones, in the hornfels, and in veins associated with sulphides. In the hornfels it is commonly developed as platy crystals parallel to the base but assumes scalenohedral forms in vugs. Some white to pink calcite from the Ophir Hill mine is manganiferous.

Dolomite ($CaCO_3.MgCO_3$) is very common both as the dominant constituent of several sedimentary formations and as a gangue mineral of the ore deposits, where it both replaces limestone and occurs as veins. Some of the dolomite is slightly ferriferous and manganiferous, approaching ankerite in composition, but no true ankerite was identified.

Siderite ($FeCO_3$) is present in very small amount as euhedral crystals, coating vugs in the hornfels of the Ophir Hill mine. It contains a very small amount of manganese.

Smithsonite ($ZnCO_3$), mostly of the ferriferous variety, is a very common mineral in the mines of Dry Canyon, from which large tonnages have been shipped as zinc ore. It is also present in small amounts in the Lion Hill and Stockton mines.

Aragonite ($CaCO_3$), the orthorhombic modification of calcium carbonate, is a rare mineral in this area. It has been identified as a supergene coating in the vugs of jasperoid from Mercur, along with an unknown phosphate, described below (p. 130), and is also present as a supergene mineral in the Bullion stope of the Honerine mine.

Cerusite ($PbCO_3$), the common oxidation product of galena, is very plentiful in the oxidized parts of the ore bodies of Dry Canyon and the Stockton area.

Malachite ($CuCO_3.Cu(OH)_2$), the common basic carbonate of copper, is rather plentiful at the mines of Dry Canyon but is present only in very small amount in Lion Hill, at Mercur, and at Stockton.

Azurite ($2CuCO_3.Cu(OH)_2$) is an uncommon oxidation product of chalcopyrite but was noted in small amounts on Lion Hill, at Ophir, and at Stockton. It is much more common in Dry Canyon.

Aurichalcite ($2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$) is a common mineral, in small quantities, in the oxidized ores of Lion Hill, Mercur, Dry Canyon, and Stockton.

Hydrozincite ($ZnCO_3.2Zn(OH)_2$) has been doubtfully identified by G. F. Loughlin from the Hidden Treasure mine.

SILICATES

Adularia. See Orthoclase.

Orthoclase ($K_2O.Al_2O_3.6SiO_2$) is one of the component minerals of the monzonites of the area. The soda-bearing variety, sanidine, is present in many of the rhyolites and some latites; the variety adularia or valencianite is very prominent in many of the hornfelses.

Microcline ($K_2O.Al_2O_3.6SiO_2$) the triclinic potash feldspar, is present in some of the monzonite stocks but is not common.

Plagioclase feldspars, chiefly of the more sodic varieties, are common minerals in nearly all the igneous rocks of the area. Essentially pure albite ($NaAlSi_3O_8$) is found in one or two of the rhyolite dikes and in very small amount in the hornfels of the Ophir Hill mine.

Hypersthene ($(Fe,Mg)O.SiO_2$) is very common in the volcanic rocks and also occurs in one of the monzonitic stocks in Tickville Gulch, where it is thought to be an indication of contamination of the magma by inclusions.

Diopside ($CaO.MgO.2SiO_2$) is a very common constituent of the hornfels of the area and is found at Ophir, Dry Canyon, Soldier Canyon, Stockton, and Settlement Canyon.

Hedenbergite ($CaO.FeO.2SiO_2$) has not been identified as a pure mineral but occurs in isomorphous mixture with diopside in pyroxene from the Hidden Treasure mine, as determined by its optical properties.

Augite, the aluminous pyroxene, is common in the monzonitic and volcanic rocks of the quadrangles. In some of the latite flows it is titanium bearing.

Wollastonite ($CaO.SiO_2$) is among the commonest of the hornfels minerals. It is very abundant in the Stockton and Soldier Canyon areas and in Dry Canyon.

Tremolite ($H_2O.2CaO.5MgO.8SiO_2$) is present in small quantities in the hornfels at Ophir, is very abundant along the Cliff fault in the Cliff mine, and is a subordinate " contact " mineral elsewhere in the quadrangles.

Actinolite ($H_2O.2CaO.5(Mg,Fe)O.8SiO_2$), the iron-bearing tremolite, is common in the Hidden Treasure mine and in Settlement Canyon.

Common hornblende is present in many of the volcanic rocks and in the monzonitic intrusives.

Nephelite ($Na_2O.Al_2O_3.2SiO_2$) occurs in the nephelite basalt flow east of Sheep Ridge and in the sills on South Mountain.

Grossularite ($3CaO.Al_2O_3.3SiO_2$) occurs in the contact rocks of Settlement and Soldier Canyons.

Andradite ($3CaO.Fe_2O_3.3SiO_2$) is the common garnet in association with the ore deposits in hornfels, at Ophir and in the Honerine mine. Some segments of the crystals are uniaxial negative and show a birefringence as great as 0.01. An andradite from the Hidden Treasure mine is titaniferous.

Olivine ($2(Mg,Fe)O.SiO_2$) occurs in the lamprophyre dikes, in the olivine basalt flow, and in the nephelite basalt sills. No forsterite was found in any of the hornfelses near igneous contacts.

Scapolite, of the variety near marialite ($3Na_2O.2NaCl.3Al_2O_3.18SiO_2$), has been doubtfully identified, in very small amount, in a hornfels found in the Hidden Treasure mine.

Vesuvianite, a basic calcium-aluminum silicate, has been identified from the Soldier Canyon contact zone and from the Honerine mine.

Zircon ($ZrO_2.SiO_2$) occurs in microscopic crystals in many of the igneous rocks of the quadrangles, as well as in the hornfels of the Ophir Hill Consolidated mine and in the Mercur jasperoid.

Topaz ($(AlF)_2SiO_4$) has been found in hornfels from the Hidden Treasure mine but is very rare.

Zoisite ($H_2O.4CaO.3Al_2O_3.6SiO_2$) has been identified optically from a hornfels specimen collected at the Calumet mine. It is a rare mineral in this area.

Clinozoisite, intermediate in composition between zoisite and epidote, has been identified in microscopic crystals in the hornfels of the Ophir Hill and Honerine mines. It, too, is uncommon.

Epidote, of the variety pistacite, rich in iron, of the general formula $H_2O.4CaO.3(Al,Fe)_2O_3.6SiO_2$, is very common in the hornfels zones at Ophir, Dry Canyon, Settlement Canyon, Soldier Canyon, and Stockton. It also occurs in the hydrothermally altered monzonites, and some is found in the lavas.

Calamine ($H_2O.2ZnO.SiO_2$) forms microscopic rosettes in the oxidized ores of Lion Hill, Dry Canyon, and the Bullion stope of the Honerine mine and in the Galena King gouge in the Argent mine. It is an uncommon mineral in this area.

Tourmaline, a complex borosilicate of aluminum and other bases, commonly containing also hydroxyl, fluorine, and alkalies, occurs in the contact zones at Mercur, in the jasperoid at Mercur and Lion Hill, in the Ophir Hill hornfels, and in the altered basal shale of the Bowman limestone. It is a widespread mineral, but nowhere is it present in any large quantity.

Apophyllite ($K_2O.8CaO.16SiO_2.16H_2O$) has been found in only one locality in the quadrangles. It occurs as very minute microscopic crystals in a veinlet in a hornfels from the drain-tunnel level of the Honerine mine.

Phillipsite ($(K_2,Ca)O.Al_2O_3.4SiO_2.4\frac{1}{2}H_2O$) is a common zeolite in the latite flows of the Fairfield quadrangle.

Analcite ($Na_2O.Al_2O_3.4SiO_2.2H_2O$) occurs as a common mineral in nephelite basalt and other volcanic rocks and in veinlets through the Settlement Canyon diorite stock.

Natrolite ($Na_2O.Al_2O_3.3SiO_2.2H_2O$) is a zeolite in the volcanic rocks of the Fairfield quadrangle. It is not common.

Thomsonite ($(Na_2,Ca)O.Al_2O_3.2SiO_2.2\frac{1}{2}H_2O$) is present in veinlets in the Settlement Canyon stock of

diorite and also in the lavas of the Fairfield quadrangle.

Epidesmine ($(Na_2,Ca)O.Al_2O_3.6SiO_2.6H_2O$) coats the joint planes in quartzite in the contact aureole of of the Soldier Creek stock.

Muscovite ($2H_2O.K_2O.3Al_2O_3.6SiO_2$) is a constituent of the Ophir formation and presumably other shaly rocks and, in the fine scaly variety sericite, occurs as a hydrothermal mineral in hornfels, jasperoid, and igneous rocks. It also occurs as a gouge clay along faults, possibly in small part due to dynamic metamorphism.

Biotite ($(H,K)_2O.2(Mg,Fe)O.Al_2O_3.3SiO_2$), the common dark mica, occurs in the rhyolite, lamprophyre, monzonitic, and latitic rocks of the area.

No effort was made during the preparation of this report to distinguish between the various members of the chlorite group that may have been encountered. All are hydrous magnesium-aluminum silicates with usually some ferrous iron. Chlorites occur in the hornfels of the Ophir Hill mine, and as alteration products of biotite in many of the igneous rocks.

Serpentine, like chlorite, is a group name, including many varieties. The composition is close to $3MgO.2SiO_2.2H_2O$, with a little ferrous iron. Antigorite, the thin lamellar variety, replaces diopside in the hornfels of the Honerine mine. Common serpentine and bastite replace the pyroxene in several of the igneous rocks.

Paligorskite, or mountain leather, a rather poorly defined hydrous magnesium-aluminum silicate, occurs along a fault in the Deseret mine, in Dry Canyon.

Iddingsite ($MgO.Fe_2O_3.3SiO_2.4H_2O$, with MgO partly replaced by CaO in the ratio of 4:1[77]) is found as pseudomorphs after olivine in the volcanic rocks of Step Mountain, in the Fairfield quadrangle. It is not a common mineral.

Talc ($H_2O.3MgO.4SiO_2$) forms an alteration product of diopside and tremolite in the Lynch dolomite at the Cliff mine. It is not a common mineral.

Sepiolite ($2H_2O.2MgO.3SiO_2$) occurs rarely as an alteration product of diopside in the hornfels of the Honerine mine.

The following clay minerals were identified during this survey, but no attempt was made at an exhaustive study of their occurrence.

Kaolinite ($2H_2O.Al_2O_3.2SiO_2$) has formed as a result of hydrothermal alteration of the Tickville rhyolite and probably of the monzonites as well. It is probably not a common clay mineral in this area.

Halloysite ($3H_2O.Al_2O_3.2SiO_2$) occurs in many of the igneous rocks as an alteration product of the feldspars.

Montmorillonite ($(Mg, Ca)O.Al_2O_3.5SiO_2.nH_2O$) has been tentatively determined by its optical properties as an oxidation product of the Ophir Hill hornfels.

Beidellite ($Al_2O_3.SiO_2.nH_2O$) was found in gouge clays encountered in the Bullion crosscut of the Honerine mine.

Chrysocolla ($CuO.SiO_2.2H_2O$) was identified in small quantities in the Lion Hill jasperoid and at the Ophir Hill mine.

Nontronite ($Fe_2O_3.3SiO_2.5H_2O$) was identified from the Bullion stope of the Honerine mine and was doubtfully determined from the Galena King gouge and in the Argent mine.

Two unidentified potash-bearing clays were found in oxidized jasperoid from Lion Hill, and Loughlin[78] reports a zinc-bearing clay, which came from the Hidden Treasure mine, but these were not further investigated.

TITANOSILICATE

Titanite ($CaO.TiO_2.SiO_2$) occurs in most of the monzonitic rocks of the quadrangles and is also present in many of the hornfelses, especially that in the Ophir Hill Consolidated mine.

PHOSPHATES, ARSENATES, VANADATES, ETC.

Apatite ($9CaO.3P_2O_5.Ca(F,Cl)_2$) is present in practically all the igneous rocks of the quadrangles, in the jasperoids, and in the hornfelses.

Dahllite, a carbonated calcium phosphate, was doubtfully identified optically in a gouge clay from the Muscatine mine, near Stockton.

Pyromorphite ($9PbO.3P_2O_5.PbCl_2$) is found as a mineral of the oxidation zone only. It occurs in many of the gossan zones at Stockton and was found in the Bullion stope of the Honerine mine, but nowhere in more than minute amounts.

Mimetite ($9PbO.3As_2O_3.PbCl_2$) was identified as an oxidation product from the gossan zone of the Honerine mine, but in small amounts only.

Collophanite ($3CaO.P_2O5.nH_2O$) occurs as metacolloidal masses in the basal shale of the Deseret limestone and in the upper part of the Madison limestone, into which it has probably been carried by ground water. In some parts of the Hidden Treasure mine the collophanite and apatite are so associated as to suggest that the collophanite has recrystallized into apatite through the agency of the hydrothermal solutions which effected the ore deposition.

An unknown phosphate associated with aragonite was found in a vug in jasperoid from Mercur. It was impossible to separate enough of the material for an analysis, but phosphate was proved to be present

[77] Ross, C. S., and Shannon, E. V., The origin, occurrence, composition, and physical properties of the mineral iddingsite: U. S. Nat. Mus. Proc., No. 2579 (vol. 67, art. 7), pp. 1–19, 1925.

[78] Loughlin, G. F., Zinc carbonate and related copper carbonate ores at Ophir, Utah: U. S. Geol. Survey Bull. 690, p. 7, 1919.

qualitatively. The mineral is white, with two cleavages, one nearly perfect, the other good. No crystal faces are developed because of the intimate intergrowth with aragonite. The mineral has the following optical properties: α 1.628, β 1.651, γ 1.678, all $\pm$0.003. It is optically positive, with medium 2 V and an extinction angle of 27° between α and the best cleavage. The acute bisectrix appears in the edge of the microscope field when the mineral lies on the better cleavage. These properties are somewhat like those of messelite, but comparison of material from the National Museum collections, kindly furnished by Dr. W. F. Foshag, shows that this has the α index much lower than that of messelite and hence is probably a distinct mineral.

The following rare phosphates, most of which are new to science, have been recently described by Larsen and Shannon [79] from a locality in Clay Canyon, Fairfield quadrangle. They were not found during this survey. They occur as nodules in limestone.

Variscite ($Al_2O_3.P_2O_5.4H_2O$).
Wardite ($CaO.2(Na,K)_2O.6Al_2O_3.4P_2O_5.17H_2O$).
Pseudowavellite ($5CaO.6Al_2O_3.4P_2O_5.18H_2O$).
Deltaite ($8CaO.5Al_2O_3.4P_2O_5.14H_2O$).
Dennisonite ($6CaO.Al_2O_3.2P_2O_5.5H_2O$).
Dehrnite ($14CaO.2(Na,K)_2O.4P_2O_5.3H_2O$).
Lewistonite ($15CaO.(Na,K)_2O,4P_2O_5.8H_2O$).
Englishite ($4CaO.(Na,K)_2O,4Al_2O_3.4P_2O_5.14H_2O$).
Millisite ($2CaO.(Na,K)_2O.6Al_2O_3.4P_2O_5.17H_2O$).
Lehiite ($5CaO.(Na,K)_2O.4Al_2O_3.4P_2O_5.12H_2O$).
Gordonite $MgO.Al_2O_3.P_2O_5.9H_2O$.

Scorodite ($Fe_2O_3.As_2O_5.4H_2O$) forms a greenish coating on jasperoid from Mercur. It is closely associated with pharmacosiderite, both being presumably derived from oxidizing arsenopyrite.

Pharmacosiderite ($3Fe_2O_3.2As_2O_5.13H_2O$) occurs in very small quantity on oxidized jasperoid from Mercur.

Beudantite ($2PbO.3Fe_2O_3.2SO_3.As_2O_5.6H_2O$) was found in small quantities as a buff powder associated with plumbojarosite in material from the gossan zone of the Honerine mine, at Stockton.

SULPHATES

Barite ($BaSO_4$) in characteristic radiating blades and plates is present in the jasperoid of Mercur and Lion Hill. It is an uncommon mineral in the ore bodies of the Honerine mine.

Anglesite ($PbSO_4$) almost invariably forms microscopic films around grains of galena which are altering to cerusite, but nowhere was any large quantity of anglesite seen.

Gypsum ($CaSO_4.2H_2O$) is widespread in small quantities as a product of the action of acid waters derived from the oxidation of sulphides on limestone. It occurs in all the mining areas.

Melanterite ($FeSO_4.7H_2O$) is found in the oxidizing ores of Mercur and Ophir and as long greenish-white needles along the Cliff fault in the old workings of the Ophir Hill mine.

Chalcanthite ($CuSO_4.5H_2O$) is a rare mineral in this area, being found only in a few specimens from the Ophir Hill mine.

Jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$) is a very widespread oxidation product of pyrite and chalcopyrite, being found in the gossan zones of all the mines. Some specimens carry a little lead.

A mineral intermediate between jarosite and alunite was found in a specimen from the old Sparrowhawk mine at Mercur. It occurs in minute hexagonal yellowish brown plates with the following optical properties: α 1.675 $\pm$0.005, β and γ 1.742 $\pm$0.003, optically negative, with 2 V = 12° $\pm$ 3°, the acute bisectrix nearly normal to the plates. The birefringence is about 0.067. The pleochroism scheme is Z = Y > X. An analysis by E. P. Henderson gave the following results:

	Analysis	Molecular ratios	
Insoluble	1. 43		
Fe_2O_3	40. 22	0. 2518	2. 83 or 3 × 0. 94
Al_2O_3	4. 01	. 0393	
SO_3	33. 15	. 4139	4. 02 or 4 × 1. 00
K_2O	9. 16	. 0972	1. 08 or 1 × 1. 08
Na_2O	. 90	. 0145	
H_2O	11. 25	. 6250	6. 07 or 6 × 1. 01
	100. 12		

This corresponds fairly well with the formula $K_2O.3R_2O_3.4SO_3.6H_2O$. Combining the alumina and the soda shows about 11 per cent of natroalunite present in isomorphous mixture. The ratio of Fe_2O_3: Al_2O_3 is 6.4:1 and that of K_2O:Na_2O is 6.7:1.

Plumbojarosite ($PbO.3Fe_2O_3.4SO_3.6H_2O$) forms dark-brown ocherous masses that consist of minute hexagonal crystals. Most of it probably contains a slight quantity of potassium jarosite isomorphously mixed with it, as the highest refractive index is slightly lower than 1.875, the ω value given by Larsen [80] for plumbojarosite. It has formed indirectly from galena, the process of alteration proceeding through the stages galena→anglesite→cerusite→plumbojarosite. On one specimen mimetite has formed from the cerusite, yielding beudantite as an end product. The plumbojarosite is widely distributed and occurs in considerable quantity on Lion Hill, in Dry Canyon, and in the Stockton area.

[79] Larsen, E. S., and Shannon, E. V., The minerals of the phosphate nodules from near Fairfield, Utah: Am. Mineralogist, vol. 15, pp. 307–337, 1930.

[80] Larsen, E. S., The microscopic determination of the nonopaque minerals: U. S. Geol. Survey Bull. 679, p. 272, 1921.

Argentojarosite ($Ag_2O.3Fe_2O_3.4SO_3.6H_2O$), the silver analogue of plumbojarosite, was found on one specimen from the Chloride Point mine on Lion Hill. It is undoubtedly a rare mineral.

ORE DEPOSITS

CLASSIFICATION

Although a genetic classification is the most fundamental for a general study of mineral deposits, a classification based primarily upon metal contents and secondarily upon forms of the deposits is the most practical for this report. Although oxidized ores have contributed considerably to the mineral output, they are so closely associated with the original sulphide ores that the two are most conveniently described together.

The major divisions of the classification are based solely on contained metals, and the subdivisions of these classes are based upon the forms of the deposits. The classification is as follows:

Gold and gold-mercury deposits:
- Bedded replacement deposits.
- Veins and fissure deposits.

Silver and silver-lead deposits: Bedded replacement deposits.

Lead-silver-zinc-copper deposits:
- Bedded replacement deposits.
- Irregular replacement deposits.
- Veins and fissure deposits.

GOLD AND GOLD-MERCURY DEPOSITS

BEDDED REPLACEMENT DEPOSITS

The bedded replacement deposits of gold and of gold and mercury are all in the southern part of the area, near the now abandoned towns of Mercur, Sunshine, and West Mercur (West Dip).

At Mercur the ores are confined to beds within the portion of the "Great Blue" limestone below the Long Trail shale member, but at Sunshine they occur in part just above the shale as well as in the lower beds, and at West Mercur they are in strata well above the Long Trail shale.

At the time of this survey none of the mines were accessible except for small portions of the near-surface workings, and the following descriptions are based almost entirely on the literature descriptive of the deposits.[81] Of these papers, the report of Butler is the latest and summarizes all the previously published papers as well as the information placed at his disposal by the officials of the Consolidated Mercur Mines Co. Butler's discussion[82] is given in the present summary, with slight modifications:

The accompanying generalized section (fig. 16) through the ore-bearing formation of the Mercur district was furnished by the Consolidated Mercur Co. It does not represent the thickness of the different formations at any given point but is an approximate average of their thickness as they have been encountered in the mine workings.

The names given for the strata in the general section of the ore-bearing formation of the Mercur area are those in common use and do not necessarily represent the character of the material—in fact, some of the beds called "porphyry" contain fossils and are generally recognized to be sedimentary.

At the base of the ore series is a massive blue limestone with beds of shaly material. These are unmineralized and practically unaltered. Overlying this is the "silver ledge,"[83] which is a cherty, rather porous mass resulting from the silicification of limestone. It carries silver and in places is a commercial ore. Locally, notably in the anticlinal body in the Brickyard and in the Geyser mines, gold ore has been mined from the silver vein.

Overlying the silver ledge is the Magazine vein. The lower part, known as the Hard Magazine, is a cherty material resulting from the silicification of limestone and in many places closely resembles the silver vein; commonly, however, it is more massive and does not possess the same porous character. The upper part, known as the Soft Magazine vein, is a shaly material, light colored and banded where oxidized and black where unoxidized. The Hard Magazine is about 20 feet thick and the Soft about 7 feet. Both carry gold and have been mined.

Overlying the Magazine vein and about 30 feet of cherty material (altered limestone) that carries little gold is the shaly Apex vein, which is about 8 feet thick and carries gold. It is overlain by about 4 feet of cherty material that is not ore and by 60 feet of relatively unaltered limestone.

The Mercur vein, which lies next above, is 20 to 25 feet thick. Its upper 4 feet is known as the Mercur vein "porphyry." Its lower 20 feet is separated into two parts by the Mercur vein footwall, a thin persistent layer of shaly material. The upper 12 feet is known as the Mercur vein and the lower 6 feet as the Lower Half. The Mercur vein is characterized by nodular cherty masses, which are present where the limestone is little altered and appear to be original in the limestone rather than a result of mineralization. In many places the Mercur vein has been altered to a cherty mass very similar to the silver ledge and the Magazine vein. The Mercur vein "porphyry," where seen in the mine, is commonly a rather massive gray rock that is soft and easily penetrated by the pick. It is of rather shaly texture and appears to be an altered sedimentary rock.

Above the Mercur vein "porphyry" is about 36 feet of lime stone followed by about 6 feet of shaly fossiliferous material, gray where oxidized and black where base. This is known as the middle streak and is gold bearing. Next above is 20 feet of limestone, above which lies the highest mineralized zone—about 40 feet of shaly and siliceous material, as follows:

[81] Hills, R. C., Ore deposits of the Camp Floyd mining district, Tooele County, Utah: Colorado Sci. Soc. Proc., Aug. 6, 1894; vol. 5, pp. 54–65, 1898. Spurr, J. E., Economic geology of the Mercur mining district, Utah, with introduction by S. F. Emmons: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, pp. 395–455, 1896. Gemmell, R. C., The Camp Floyd mining district and the Mercur mines, Utah: Eng. and Min. Jour., vol. 63, pp. 403–404, 1897. Dern, G. H., The geology of Mercur: Mines and Minerals, vol. 24, pp. 543–545, 1904. Palmer, L. A., Milling practices at the Consolidated Mercur: Salt Lake Min. Rev., vol. 10, p. 16, 1909. Allen, R. H., Mines and mills of the Consolidated Mercur Mines Co.: Eng. and Min. Jour., vol. 89, pp. 1273–1277, 1910. Maguire, Don, and Howard, L. O., The romance of a famous gold mine: Salt Lake Min. Rev., June 15, 1913, pp. 13–15; June 30, 1913, pp. 13–17; July 15, 1913, pp. 10–15. Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 388–395, 1920.

[82] Butler, B. S., op. cit., pp. 392–395.

[83] The silver ledge is jasperoid and has been described on pp. 97–101. It is properly called, from its topographic expression, a ledge, but the name ledge is hardly applicable to the gold-bearing ore beds, as they are not at all conspicuous in the topography.—J. G.

Upper vein footwall, 5 feet; upper vein, 8 feet; upper vein porphyry, 20 feet; shale, 8 feet. Overlying this is the massive blue limestone.

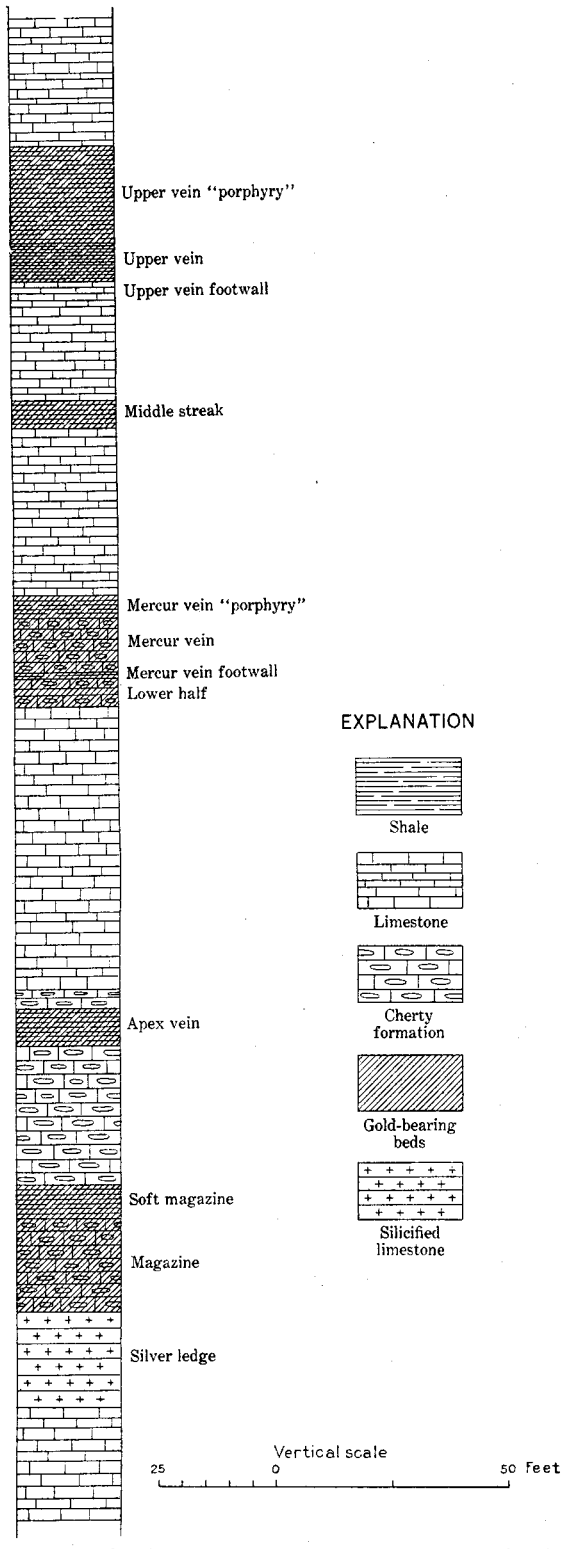


FIGURE 16.—Generalized section of the ore beds in the Mercur district. After Butler

The beds are cut by a series of fissures striking east of north and dipping very steeply west. The ore shoots follow approximately the intersection of the fissures with the ore beds. The relation between ore bodies and fissures is, however, less striking in this district than in the Ophir and Stockton districts.

Spurr believed that both the gold and silver "ledges" were localized along sills of Eagle Hill rhyolite and indicated the outcrops of the supposed sills on his map. The detailed mapping of the surface geology during this survey has failed to confirm the presence of these sills, and, in the opinion of the writer, the rocks mapped by Spurr as porphyry are, except near the Sacramento mine, not igneous but merely weathered limestone, perhaps in part hydrothermally altered as well.

Butler says:[84]

There has been much mining development in the district since the time of Spurr's investigation, and exposures in the ore zone are far more extensive, giving a correspondingly favorable opportunity for observation. The writer was informed by the management of the Consolidated Mercur Mines Co. that developments had failed to show the presence of thin porphyry sheets in connection with the ore zones, and an examination of some of the best exposures in the mine failed to disclose them. Most of the rocks are much altered, and a sheet of altered porphyry might well be mistaken for an altered sediment, but it was possible to trace several supposed porphyry beds along the strike into unmistakable sedimentary rock. Moreover, several shale beds, commonly called "porphyry," carry abundant fossils that leave no doubt of their sedimentary origin.

The writer did not spend sufficient time in the district to follow out the supposed porphyry horizons in detail. At several points he was unable to recognize any porphyry and believes that porphyry at these horizons does not form continuous sheets extending out from the main masses. * * *

Alteration.—The alteration of the rocks is largely dependent on their original character. Many of the limestone beds are silicified to a cherty quartz (jasperoid) with small amounts of sericite. The shaly beds appear to have suffered less alteration, though they have probably gained silica and possibly some potassium, which have formed sericite. The potassium, however, may have been originally present in the shale. Most of the ore contains also considerable barite and secondary calcite. The principal metallic minerals are pyrite, realgar with some orpiment, and cinnabar.

The following analysis[85] is of sulphide ore from the Grasshopper shaft of the Golden Gate mine:

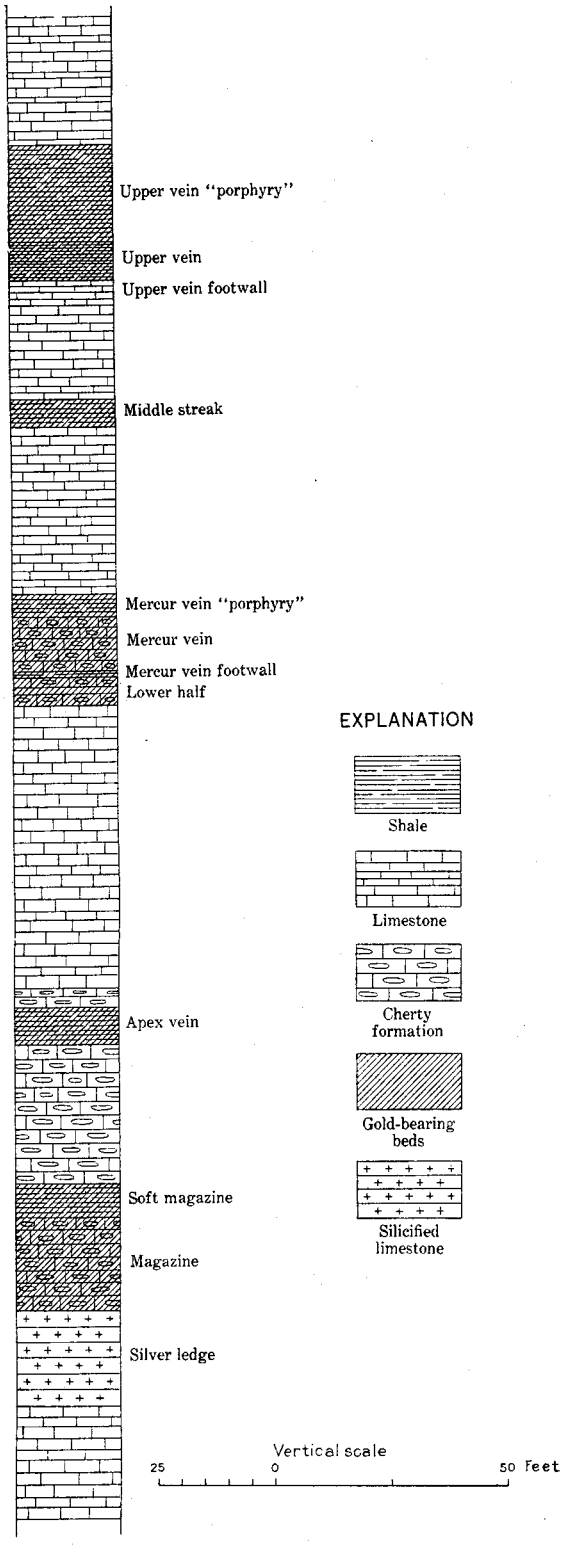
Analysis of Golden Gate ore

[W. F. Hillebrand, analyst]

	Per cent
Silicon dioxide (SiO_2)	66.42
Titanium dioxide (TiO_2)	.85
Aluminum sesquioxide (Al_2O_3)	14.85
Iron sesquioxide (Fe_2O_3) + Iron protoxide (FeO)	.31
Iron disulphide (FeS_2)	6.60
Calcium oxide (CaO)	.35
Barium oxide (BaO)	.19
Magnesium oxide (MgO)	.83
Potassium oxide (K_2O)	2.73
Sodium oxide (Na_2O)	.13
Lithium oxide (Li_2O)	Very strong trace.
Water below 110° C	.53

[84] Butler, B. S., op. cit., pp. 390, 393–395.
[85] Spurr, J. E., op. cit., p. 424.

Upper vein footwall, 5 feet; upper vein, 8 feet; upper vein porphyry, 20 feet; shale, 8 feet. Overlying this is the massive blue limestone.



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The writer did not spend sufficient time in the district to follow out the supposed porphyry horizons in detail. At several points he was unable to recognize any porphyry and believes that porphyry at these horizons does not form continuous sheets extending out from the main masses. * * *

Alteration.—The alteration of the rocks is largely dependent on their original character. Many of the limestone beds are silicified to a cherty quartz (jasperoid) with small amounts of sericite. The shaly beds appear to have suffered less alteration, though they have probably gained silica and possibly some potassium, which have formed sericite. The potassium, however, may have been originally present in the shale. Most of the ore contains also considerable barite and secondary calcite. The principal metallic minerals are pyrite, realgar with some orpiment, and cinnabar.

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Analysis of Golden Gate ore

[W. F. Hillebrand, analyst]

	Per cent
Silicon dioxide (SiO_2)	66.42
Titanium dioxide (TiO_2)	.85
Aluminum sesquioxide (Al_2O_3)	14.85
Iron sesquioxide (Fe_2O_3)	.31
Iron protoxide (FeO)	
Iron disulphide (FeS_2)	6.60
Calcium oxide (CaO)	.35
Barium oxide (BaO)	.19
Magnesium oxide (MgO)	.83
Potassium oxide (K_2O)	2.73
Sodium oxide (Na_2O)	.13
Lithium oxide (Li_2O)	Very strong trace.
Water below 110° C	.53

[84] Butler, B. S., op. cit., pp. 390, 393–395.
[85] Spurr, J. E., op. cit., p. 424.

	Per cent
Water above 110° C	3.65
Sulphur trioxide (SO_3)	.31
Phosphorus pentoxide (P_2O_5)	.04
Arsenic pentoxide (As_2O_5)	.41
Arsenic disulphide (As_2S_2)	1.75
Tellurium (Te)	[a] Trace (?)
	99.95

[a] In the opinion of Doctor Hillebrand there was tellurium in the sample analyzed, although on account of the small quantity obtained he was unable to submit it to a special test, and therefore thought best to indicate this lack of certainty by the interrogation mark.

The alteration of the rock and the addition of gangue minerals in the ore shoots have not been sufficient to permit a reliable estimate of the value of the ore from its appearance. Much good ore does not perceptibly differ from waste, and it is necessary to sample and assay to determine its value. Realgar or cinnabar usually indicates good ore, but their absence is no proof of barrenness.

There is commonly a considerable difference in appearance between the oxidized and unoxidized (base) ore. The oxidized ore is generally light colored and more friable than the unoxidized; it lacks sulphides and contains sulphates, including scorodite, melanterite, jarosite, and gypsum.

The following is an analysis of oxidized gold ore from the stope of the Apex tunnel in the Mercur mine.[86]

Analysis of Mercur ore

[W. F. Hillebrand, analyst]

	Per cent
Silicon dioxide (SiO_2)	89.24
Titanium dioxide (TiO_2)	.38
Aluminum sesquioxide (Al_2O_3)	2.02
Iron sesquioxide (Fe_2O_3)	1.45
Iron protoxide (FeO)	.62
Calcium oxide (CaO)	.95
Barium oxide (BaO)	.72
Magnesium oxide (MgO)	.23
Potassium oxide (K_2O)	.47
Sodium oxide (Na_2O)	.08
Lithium oxide (LiO)	Strong trace.
Water below 110° C	.56
Water above 110° C	1.16
Sulphur trioxide (SO_3)	.44
Phosphorus pentoxide (P_2O_5)	.08
Arsenic pentoxide (As_2O_5)	1.60
Molybdenum (Mo)	(?)
Tellurium (Te)	(?)
	100.00

Occurrence of the gold.—Gold is never visible in either the oxidized or unoxidized ores of the district, and the form in which it is present has never been positively determined, though Spurr thinks it is present as the telluride in the base ore and as free gold, though probably in some special condition, in the oxidized ore. It has been suggested by Spurr and others that the gold of the Mercur district occurs in an allotropic form that will not readily amalgamate with mercury but is attacked by chlorine and potassium cyanide. Unfortunately gold has never been found in the oxidized ores of the Mercur district in sufficient concentration to make a careful chemical examination of its condition possible.

Experiments carried on for the Consolidated Mercur Mines Co. indicate an association of the carbon of the ore with the gold. The following are the carbon content and the insoluble gold in different types of ore examined:

Association of carbon and insoluble gold in Mercur ores

	Carbon (per cent)	Insoluble gold (per ton)
Oxidized ore	0.105	$0.40
Raw base (arsenic)	.358	.90
Pyritic base	.450	All but trace.

The insoluble gold given is an average of a number of tests made on raw ore after lime oxidation by agitation of 5 pounds of ore, ground to pass 200-mesh, by air in a 2-pound cyanide solution with 25 pounds of lime. The different ores were boiled for a week, the carbon scum being skimmed repeatedly. The oxidized ore gave almost no carbon, but the pyritic base gave a large amount. An analysis of the scum gave 10.3 per cent free carbon and $9.10 gold; after agitation in potassium aurocyanide ($KAuCy_2$) solution and washing it assayed $90.60 per ton.

There is considerable concentration of gold in the carbon content of the ore, as shown by head assay after boiling: Raw pyrite base, $3.31; after boiling, $2.27.

It is of course well known that carbon will precipitate gold from solution, though no general agreement has been reached as to the cause of such precipitation; and it has also been shown[87] that in gold-silver cyanide solutions carbon precipitates gold more readily than silver and that little silver precipitates while gold remains in solution. Spurr has shown that the gold is not particularly associated with the sulphides, and the data at hand point to its association with the carbon of the rocks.

Down the dip the character of the ore does not change notably after the sulphide ore has been reached, but the gold content decreases in a short distance from good ore to material too low in gold for commercial treatment.

The maximum distance from the outcrop to which ore has been developed is about 1,500 feet. The great bulk of the ore, however, has come from within a few hundred feet of the outcrop.

The decrease in the gold content of the ore with increasing distance from the surface suggests enrichment by surface solutions. On the other hand, the ores at or very near the surface are as rich as at any greater depth, and in the absence of an overlying leached zone it is not easy to find a source for such enrichment.

The grade of the ore is low. In 1902 it averaged $5.72 per ton, of which $1.19 was lost in the tailings. From that time the average of the ore treated has decreased till in years just previous to 1912 it was as low as $3.50 per ton, with 80 to 90 cents lost in tailings.

The average grade of the ore mined was, of course, dependent on the cost of extraction and treatment, for as low-grade rock was taken as could be profitably handled.

Although mercury occurs in nearly all the Mercur ores and has given its name to the camp, the Sacra-

[86] Spurr, J. E., op. cit., p. 426.

[87] Cowles, R. K., Precipitation of gold and silver by carbon: Min. and Sci. Press, vol. 105, p. 730, 1912.

mento is the only mine in the district from which it has been produced in commercial quantities, and this mine was inaccessible when the writer visited the district. Boutwell[88] has described the deposit as follows:

> The ore is earthy cinnabar with a siliceous gangue and yields 6 per cent on an average and 80 per cent in picked samples. It occurs in bands in an altered cherty limestone adjacent to a dike and to a fracture zone. In general the portion of this limestone which bears quicksilver constitutes a lenticular shoot measuring about 10 feet in thickness, 50 feet along the strike and 140 feet on the dip. This lens is coincident with the bedding of the limestone along the middle and major portion of its dip, but at its upper edge it bends and cuts abruptly across the bedding, while at its lower edge, on approaching the dike and fracture on its dip, it drops sharply down across the bedding, pinching out at both its upper and lower terminations to thin edges.

The ore deposits of the Sunshine district, about 3 miles south of Mercur, are apparently very similar in all respects to those of Mercur, though their stratigraphic relations are not identical. The mines are practically inaccessible, and no new information regarding them was obtained during this survey.

FISSURE AND VEIN DEPOSITS

The shoots of the Mercur gold and gold-mercury ores are distributed along definite fissures, and there were a few places in which the wall rocks of the fissures were minable for some feet below the ore horizons. Fissure filling, however, was negligible, essentially all the ore being formed by impregnation or replacement of the country rock. Nevertheless these fissures were of fundamental importance in localizing the deposits, as was shown by Spurr.[89]

The writer could obtain no information relative to the extent of fissuring in the deposits at Sunshine. At West Dip the localization of the mines along the West Mercur fault for about 2 miles seems to indicate a definite control of mineralization by this fault. No adequate descriptions of the ore bodies of these mines were obtained, and the mines are all inaccessible except for a few tens of feet along their inclined shafts. Nevertheless, the fact that a considerable difference exists in the stratigraphic position of the rocks along the footwall of this fault within the mineralized area seems to indicate that the mineralization was related to the fault rather than to any particularly favorable strata. Presumably, from the scant descriptions the writer was able to obtain, the ore was, like that at Mercur, formed by impregnation and possibly replacement of the wall rocks. The much closer dependence of the deposits upon the fissuring along the fault here than at Mercur is a matter of inference only.

[88] Boutwell, J. M., Quicksilver: U. S. Geol. Survey Mineral Resources, 1906, p. 494, 1907.

[89] Spurr, J. E., op. cit., pp. 435–437.

SILVER AND SILVER-LEAD DEPOSITS

BEDDED REPLACEMENT DEPOSITS

Bedded replacement deposits of silver and of silver and lead occur near Mercur, in a narrow zone extending to the north end of Lion Hill, and at the Lakes of Killarney mine, in the foothill belt between Ophir and Dry Canyons. In all these localities the ore minerals are localized within or beneath bodies of jasperoid which crudely parallel the stratification.

MERCUR-LION HILL AREA

The distribution and stratigraphic relations of the jasperoid bodies in the area between Mercur and Lion Hill are described on pages 97–98. At both Eagle Hill on the south and Lion Hill on the north the jasperoid appears to be closely associated with porphyry bodies, but between these points no such association is evident. The silver mineralization of the jasperoid was essentially coextensive with this widespread type of alteration, according to assays reported by Spurr,[90] but the areas in which it was sufficiently concentrated to furnish minable ores are very small. A factor of probably great importance in bringing about this variability was the long continuing brecciation of the jasperoid during crystallization from the colloidal phase (pp. 97–101), which developed constantly changing passages for the mineralizing solutions during ore deposition. Thus some parts of the jasperoid were closed to free circulation of ore solutions, while other parts were especially favored. It is probable that more remote changes in the course of circulating solutions also operated to the same end.

Whatever the control may have been, it is certain that the important mineralization was very sporadic. Despite the great richness of the oxidized ores of such mines as the old Carrie Steele and Sparrowhawk, at Mercur, and the Lion, Rockwell, Tiger, Chloride Point, and Zella, on Lion Hill, nearly all the masses of jasperoid are of so very low value as to be quite unworkable.

The ores are characteristically silver ores, with some gold, arsenic, antimony, lead, zinc, and manganese. The principal gangue mineral is the silica of the jasperoid, but ore also occurs in the otherwise unaltered limestone beneath. The ores range in tenor from very high grade, carrying thousands of ounces to the ton, to low-grade milling ores.

The minerals other than silica that occur in significant quantities in the jasperoid are few. Of hypogene minerals barite, calcite, sericite (muscovite), tourmaline, chalcopyrite, stibnite, chlorite, carbon, and probably hematite are the only conspicuous ones, and

[90] Spurr, J. E., op. cit., p. 394.

they are quantitatively very subordinate. Spurr [91] reports pyrite in addition, and it is probably very widespread in very fine grains. No primary silver minerals were observed either at Mercur or on Lion Hill. None of these jasperoid ore bodies have been worked below the zone of oxidation, and the silver is present as cerargyrite and in some places as argentojarosite. It is accompanied by the oxidation products of the other minerals in jasperoid—jarosite, malachite, azurite, and "limonite." At Mercur scorodite also is found, but according to Spurr this mineral is probably derived by leaching from realgar of the overlying "gold ledge." Butler reports arsenic in some oxidized ore from Lion Hill. On Lion Hill plumbojarosite, cerusite, and aurichalcite also occur. The absence of any lead minerals accompanying the silver at Mercur is very remarkable, in view of the usual association of lead and silver and especially their occurrence together in otherwise very similar deposits on Lion Hill.

The ore bodies have in general blanket shapes, following the jasperoid or the limestone immediately beneath the silica masses, but they also have tendencies to run parallel to fissures. This feature is very evident in most of the old workings, both at Mercur and on Lion Hill, and is clearly seen on the mine map of the Chloride Point area in Plate 25. These workings are almost entirely inaccessible now, but their trends are generally north-south, parallel to notable fissuring in the limestones.

Most of the ore bodies that have been worked have been developed within a few tens of feet of the surface. Well-marked fissures are reported by Spurr to extend below the jasperoid, but they are not ore bearing, although locally filled with calcite.

FOOTHILL AREA BETWEEN OPHIR AND DRY CANYONS

Small bodies of jasperoid occur in the area of the Lakes of Killarney mine, replacing two beds of limestone close to the top of the "Great Blue" limestone, just beneath the Manning Canyon shale. The ore occurs in jasperoid and is especially rich along fissures that trend nearly north and dip steeply east. Silver very little gold, and traces of copper and zinc occur in the ore. Assays as high as 600 ounces of silver to the ton have been reported, according to James Quinn, superintendent.

LEAD-SILVER-ZINC-COPPER DEPOSITS

BEDDED REPLACEMENT DEPOSITS

Most of the mines (other than gold) in these quadrangles have exploited bedded replacement deposits either in hornfels or in limestone. These deposits are as a rule sharply limited to certain particularly favorable limestone strata, though a few less regular bodies transgress into the beds that normally form the foot or hanging wall. In addition to the localization within certain beds, nearly all the deposits are controlled by fissures. (See pl. 32.) Thus the typical body is a mass with its longest axis along the intersection of a fissure and a bed, a secondary axis in the plane of the bed, and its shortest dimension normal to the bed. Some of the replacement masses reach lengths of over 2,000 feet in the Ophir Hill Consolidated mine and over 1,600 feet in the Honerine. The larger bodies extend along the bedding normal to the fissures for distances exceeding 100 feet in these mines also, but these dimensions are unusual, 30 feet being a more ordinary width. The greatest thickness known is 40 feet, in the "Big vein" of the Ophir Hill Consolidated mine, but 6 to 10 feet is much more common.

Variations in the size of the ore bodies along the central fissures are usually gradual, but away from the fissures the ore bodies are far less regular. In some bodies the replacement has been complete within the favorable limestone up to a nearly straight side wall; elsewhere the mineralization became sporadic away from the fissure, so that the ore bodies fray out at the edges, especially in the hornfels. Most of the ore bodies fray out along their pitch length as well, but the changes in this direction are generally far more gradual than in the others.

The most abundant hypogene sulphide minerals in the bedded replacement bodies are galena, sphalerite, chalcopyrite, microscopic argentite, tennantite, pyrite, and pyrrhotite, of which the tennantite and pyrrhotite are confined, in the writer's experience, to the Ophir Hill Consolidated mine. Cerusite, plumbojarosite, anglesite, jarosite, "limonite," aurichalcite, smithsonite, calamine, hydrozincite, malachite, azurite, pyrolite, psilomelane, and wad occur as oxidation minerals, and probably cerargyrite also, although none was found associated with these deposits during this survey.

So far as could be determined, there was very little migration of the metals during the oxidation of the sulphide ores. In view of the high calcite content of the wall rocks this slight migration is all that would be expected. It is probable that near the surface impoverishment in copper and zinc of all the mixed sulphide bodies with concomitant enrichment in lead and silver was a characteristic feature, but the surficial oxidized ores have long ago been mined and are not available for study.

The tenor of these ores is in general low, but this is compensated by the persistence of the shoots. The oxidized ores mined in the early days were commonly of very high grade, running 50 to 60 per cent of lead and from 20 to 90 ounces of silver to the ton in the Rush Valley (Stockton) mines, and occasionally shoots

[91] Spurr, J. E., op. cit., p. 393.

of sulphide ores are still found that approach this grade. More usual ore from Stockton runs 6 to 20 per cent of lead, 2 to 12 per cent of zinc, and 2 to 8 ounces of silver and 20 to 60 cents in gold to the ton. The smaller ore bodies in the Buffalo tunnel on Lion Hill run 40 to 50 per cent of lead with about 1 ounce of silver to 1 per cent of lead, and occasional carload lots carry $3.50 to the ton in gold. The great ore bodies of the Ophir Hill Consolidated mine averaged, over a period of years, about 6 per cent of lead, 5.5 ounces of silver to the ton, 4 per cent of zinc, and 1.3 per cent of copper, with negligible gold.

IRREGULAR REPLACEMENT DEPOSITS

In addition to the regular replacement deposits, each of which is essentially confined to a single limestone bed, there are a few deposits, of which the old Chicago and Hidden Treasure mines are the chief examples, that have a pipelike form and crosscut the bedding. These deposits are in the upper part of the Madison limestone, beneath the shale and phosphate beds that form the base of the Deseret formation. Instead of being limited to a small part of the limestone, however, the ore bodies are pipelike masses, controlled apparently by openings along north-south fissures and extending through a stratigraphic interval of 200 feet. The Hidden Treasure ore was found chiefly within 75 to 100 feet of the shale, and at some places the stopes were that high and reached a maximum width of 50 feet, the ore in such places being governed by a group of fissures. The ore body dropped lower in the strata as it was followed north. In the Sacramento incline the ore body is at least 300 feet stratigraphically beneath the shale that forms the back of the stopes near the surface.

The Chicago shoots were entirely pipelike, apparently not being controlled in the least by the bedding. On the outcrop the shoots were on the same fissures as the Hidden Treasure and about 200 feet lower stratigraphically. Toward the north, however, they rose and finally joined the Hidden Treasure shoots. These Chicago ore bodies were smaller, being on an average only 2 or 3 feet in diameter. Similar pipelike masses occurred in the Kearsarge mine.

In the Eureka-Ophir mine, just north of the Hidden Treasure, the ore body, according to Mr. D. W. Lynch, was a very irregular replacement deposit occurring along generally north-south fissures in a brecciated mass of porphyry and limestone above the shale at the base of the Deseret limestone. The mine was almost wholly inaccessible at the time of this survey, so that the details of form and relations of the deposit could not be ascertained.

The mineralogy of these deposits is essentially the same as that of the bedded replacement deposits. The principal difference is that these deposits, through the accident of their topographic position, are almost entirely oxidized, although sulphides are found in small amount near the surface and increase in quantity with depth.

In the Hidden Treasure mine there seems to have been some migration of the zinc and copper oxidation products into the walls of the sulphide ore bodies, but, while leading to the separation of these metals into sheaths around the remaining lead carbonates, the migration appears to have been very slight. The Hidden Treasure oxidized ore runs about 20 per cent of lead (maximum 40 per cent), 18 ounces of silver to the ton, and 4 to 6 per cent of zinc. The copper carbonate ores run as high as 22 per cent of copper. The zinc carbonate ores run about 40 per cent of zinc, perhaps 1 per cent of copper, and only 2 ounces of silver to the ton. The sulphide ores run about 30 per cent of zinc, 14 per cent of lead, and 8 to 10 ounces of silver to the ton. The gold tenor rarely exceeds 50 cents to the ton.

FISSURE DEPOSITS

The ores occurring as clear-cut fissure fillings are of small value, although they are present in many areas. Replacement veins are richer, and some very high grade ores have been recovered from them. These deposits are in the form of tabular replacement masses parallel to and including the fissures. Examples are found in the Jim Fisk, Salvation-Hercules, Katherine, Mono, Cliff, and Kearsarge mines. Although some of these ore bodies were very rich they were all small, rarely exceeding a foot or two in width, a few tens of feet in height, and 300 or 400 feet in length. Similar deposits have been mined in the Honerine mine.

The mineralogy of these deposits is very similar to that of the bedded ores, except that as a rule these deposits carry greater quantities of gold.

THE MINES

CAMP FLOYD DISTRICT

MERCUR AREA

CONSOLIDATED MERCUR

The Consolidated Mercur mines were located at Mercur, the principal workings on the south side of Mercur Canyon but other workings on the north side. The company owned about 944 acres of mining claims, of which about 400 acres was in the principal mineralized belt of the camp. The mines, when active, were served by the Salt Lake & Mercur Railroad, which connected by way of Manning Canyon with the Los Angeles & Salt Lake Railroad at Fairfield Junction. The railroad was dismantled in 1914.

Developments and production.—The mines of the Mercur area were all caved and inaccessible at the time of this survey in 1926, having been abandoned in 1913. No accurate maps of the developments of the property were available, but it is known that the workings were very extensive and ran to many thousands of feet. The total output of the Consolidated Mercur Mines Co. and its predecessors, the Delamar Mercur Co. and the Mercur Gold Mining & Milling Co., was 4,336,621 tons of ore, yielding about $16,500,000 in gold. Dividends amounted to $3,445,312.

Geology.—The Consolidated Mercur mines are all in the "Great Blue" limestone below the Long Trail shale member. The ore was the result of replacement and impregnation of limestone beds, associated with the jasperoid type of alteration. Six beds were locally ore bearing, but the principal output was obtained from the upper three of these—the "Mercur vein," the "Middle Streak," and the "Upper vein." The beds dip 10°–30° E., averaging perhaps 25° in the mines. They strike a few degrees west of north as a rule, though there are some "bedding rolls." They form a part of the eastern limb of the Ophir anticline.

Owing to the impossibility of access to the mines, the writer can add no detailed mine description to the discussion of the mineralization at Mercur quoted from Butler on page 132.

GEYSER-MARION

The Geyser-Marion mine (Franklin lease) is just north of the Mercur town site. It is one of the oldest mines in the district. The Marion mill was the first in the district, operating on silver ores in 1872–73, 1880, and 1889. In 1893 it was changed to a cyanide plant equipped to treat 50 tons of gold ore a day. The adjoining Geyser mine was combined with the Marion in 1897, but the property did not prosper and was sold at sheriff's sale shortly after 1900. It was later operated as the Franklin lease up to 1913 but was not a success. The total production of gold was probably about $500,000.

Like the other mines at Mercur, the Geyser-Marion was caved and inaccessible at the time of this survey in 1926, so that no new information was obtained regarding it. No map of the workings was obtainable, but they were rather extensive. The mine is known to be in the same stratigraphic horizons as the Consolidated Mercur mines, and its ore was also very like that of the Consolidated Mercur.

SACRAMENTO

The Sacramento mine is about three-quarters of a mile southwest of Mercur, in the gulch draining the north slope of Sunrise Hill. The mine began commercial operations in 1895. It operated for about 12 years, during which about $1,500,000 in gold and over 3,000 flasks of mercury were produced. It was the only mine of the district from which mercury was obtained commercially. The workings are inaccessible, but the accompanying map (pl. 26), kindly supplied by former officials of the mine, shows that they were rather extensive. About 600,000 tons of ore was extracted.

The mine is in the lower part of the "Great Blue" limestone, at the same stratigraphic horizons as the Consolidated Mercur mines. The beds dip about 30° E., on the east limb of the Ophir anticline. The porphyry intrusion of Sunrise Hill cuts through the western part of the mine. The ore is reported to have resembled that of the Consolidated Mercur mines but carried a considerably greater proportion of mercury, some assays running 8 per cent.

SUNSHINE AREA

OVERLAND

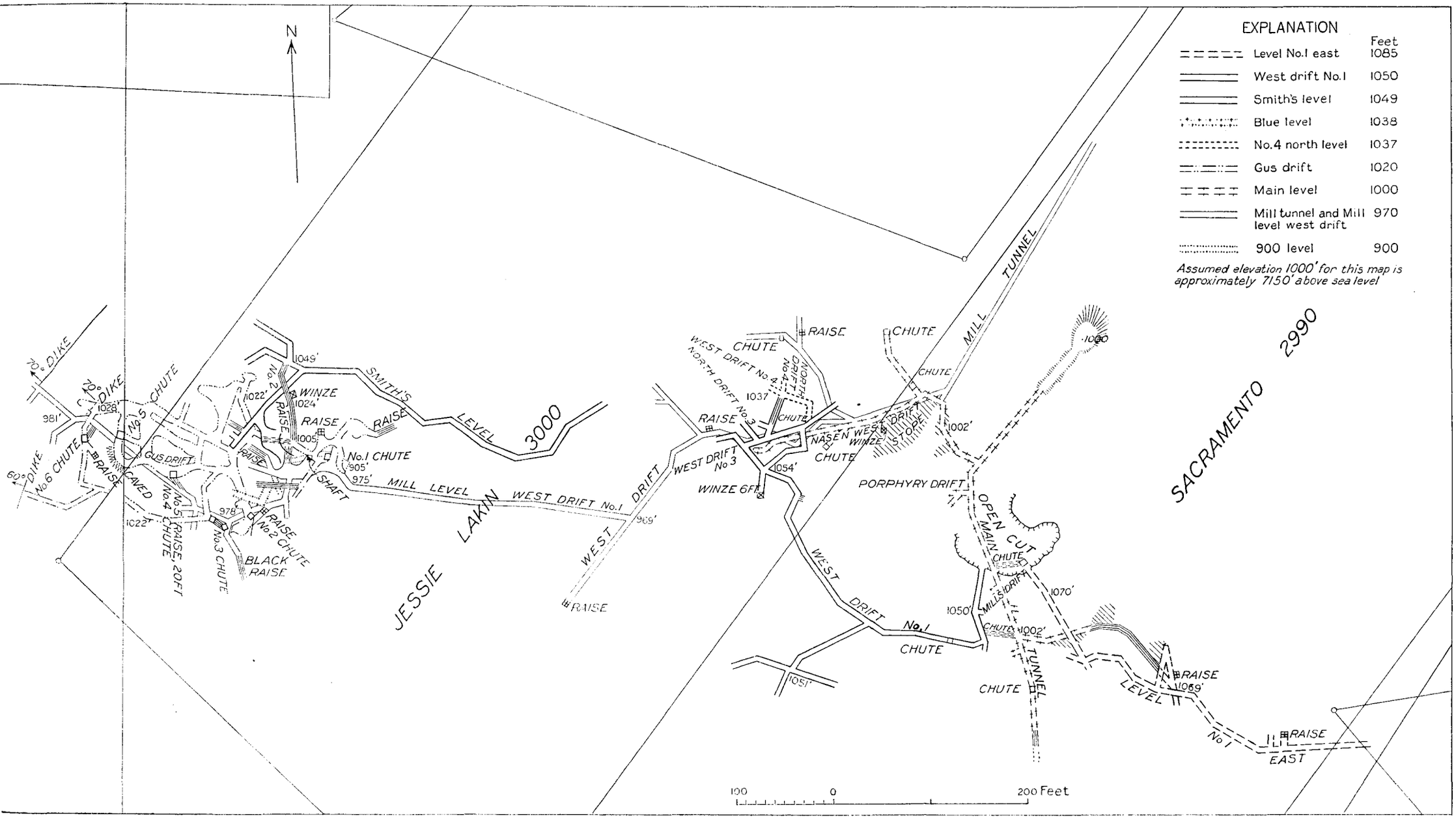
The Overland mine is about half a mile northeast of the Sunshine, on the east side of Overland Gulch. It was operated at intervals from 1898 to 1905, in the last years under a receiver. The production is estimated at $219,646, from 156,000 tons of ore.

The mine is developed on the upper levels by an inclined shaft and on the lower levels by a vertical shaft which cut the ore bed at 1,600 feet on the dip. The mine is in the "Great Blue" limestone beneath the Long Trail shale member, on the east flank of the Ophir anticline, where the dip is about 35°–40° E. The workings were inaccessible in 1926, and no description of them can be given. The ore is described as practically identical with that at Mercur.

SUNSHINE

The Sunshine mine is just south of the town of Sunshine, a little more than 3 miles south of Mercur. It operated from December, 1895, to October, 1896, for a short time in 1898–99, in 1902, and in 1909–10, when it was closed, the ore supply being considered exhausted. The total production is believed to have been about $221,000 in gold.

The mine is just below the Long Trail shale member of the "Great Blue" limestone and was developed by an incline trending N. 75° E. and having a slope of 32°, with the bedding, which dips east, on the east limb of the Ophir anticline. The mine was badly caved at the time of this survey, in 1926, and but little of it was accessible. The ore appears to have occurred at two horizons, approximately 150 feet apart stratigraphically, each immediately beneath a carbonaceous shale bed. Some fissures trending N. 45° W. were followed by drifts. Presumably the ore was associated with these fissures, but this is not known to be true.



MAP OF THE WORKINGS OF THE SACRAMENTO MINE, MERCUR AREA

The ore greatly resembled that at Mercur but was in beds lying somewhat higher in the stratigraphic column.

WEST MERCUR OR WEST DIP AREA

DAISY (NORMA)

The Daisy mine, later renamed the Norma, is just south of the abandoned site of West Mercur. It was discovered shortly after the first successful gold mining in the Mercur district, and construction of a mill was begun in 1897. It was the first mine at West Mercur to ship cyanide precipitates, but little success was attained and in February, 1900, the mine was handed over to the miners for them to earn their back wages from it.[92] In July, 1900, it went into the hands of a receiver. It was overhauled at various times in later years, and the company was finally reorganized as the Norma Gold Mining Co. Operations were renewed in 1913, but the mine has been abandoned since the complete destruction of the mill by fire in 1917.

The mine was developed by two inclined shafts, each about 700 feet deep, with numerous drifts connecting them. The shafts were sunk along the West Mercur fault (see fig. 9) with the "Great Blue" limestone as the footwall and Quaternary alluvium as the hanging wall, at least for the few score feet of the shafts that are now accessible. The mine is caved almost to the surface, and no new information regarding its geology was obtained during this survey. The ore is described by former employees of the mine as strongly resembling that of Mercur. It occurred along the West Mercur fault, presumably associated with this fault rather than any particularly favorable bed.

The ore ran between $4 and $8 to the ton. It was difficult to treat. The production of the mine was somewhat more than $75,000.

LA CIGALE

The La Cigale mine is about a mile north of the abandoned site of West Mercur and about 4 miles west of Mercur. It was first developed in 1897 by three inclined shafts along the West Mercur fault, with levels at 100 and 260 feet below the surface. It is not known what additional development work was done in the two years following, but the mine was abandoned at the end of 1899. In 1926 it was so badly caved that the workings were inaccessible. The workings have been described[93] as localized along a shear zone, and certainly the shafts expose and follow the West Mercur fault (see fig. 10), so that presumably the ore was related to this major fault. The fault dips west and as far down the incline as can be seen, about 150 feet, exposes only alluvium in the hanging wall. The long strike distance through which the fault zone was assayed and found to be mineralized leads to the conclusions that the fault was probably of premineral age and that the mineralization was not confined to certain beds as at Mercur but extended to the breccia zone along the fault. However, the "Great Blue" limestone, which forms the footwall of the fault, dips essentially parallel to it, so that the localization of the ore along the fault may possibly have been fortuitous and due merely to accidental coincidence with a susceptible limestone bed. The horizon in the "Great Blue" limestone just below the fault is much higher than that of the productive strata at Mercur, being several hundred feet above the Long Trail shale member instead of below it.

The ore is described as essentially the same as that of Mercur, and assay values averaging over $6 a ton were reported by the company. In view of the success of the Mercur mines with ore of this grade, it is probable that such assays were not truly representative of the ore as mined, for if they were the venture should have prospered better than it did.

OPHIR DISTRICT

LION HILL AREA

BUFFALO

The Buffalo mine is on the southeast side of Lion Hill and has been worked through two adits near the upper end of Long Trail Gulch. It is reached by wagon road up Long Trail Gulch from Ophir, a distance of somewhat less than 2 miles.

Development and production.—The mine is developed through two adits about 280 feet vertically apart, connected by means of an inclined raise and drifts. The total workings probably exceed 6,000 feet in length, but much of the older part of the mine is caved and inaccessible. The principal workings date from the early days of mining in the district, and as in most of the mines whose principal production was made in those days, the total output can only be guessed at. It is known to exceed $150,000 and may be very much greater. For a number of years before the time of this survey, the mine had been under lease to George St. Clair.

Geology.—The Buffalo mine (see pl. 25) is situated in the lower part of the "Great Blue" limestone, below the Long Trail shale member. Two sills of "Birdseye" porphyry are cut by the lower tunnel, but the ore seems to bear no relation to them. The beds in the mine have generally an even inclination, striking N. 25° E. and dipping about 25° SE.

The ore occurs in pipes and in bedded deposits that replace the limestone. In the upper workings the ore shoots connected with those of the Chloride Point

[92] Howard, L. O., Cyanidation in the Mercur district of Utah: Salt Lake Min. Rev., October, 1913.

[93] Thompson, R. V., oral communication.

mine, and large stopes were developed in connection with the jasperoid wall rock, but on the lower levels there is little jasperoid. The principal fissures in the lower workings of the mine are those followed by the McClellan and St. Clair inclines. The McClellan incline trends N. 70° E., the St. Clair S. 65° E. The Clark incline, just west of the McClellan, extends up from the lower or Buffalo tunnel level as a continuation of the drift from the St. Clair incline and connects, on a level 200 feet higher, with the East Side tunnel. The connection is very narrow and tortuous and was not surveyed, so is not shown in Plate 25. The ore followed fissures and locally extended along the bedding for 6 or 8 feet from the fissures. A shoot on the St. Clair fissure was 2 feet wide and 12 feet high, of solid galena, but pinched out when followed. On the upper levels the ore was all oxidized, but in the lower part of the mine it is chiefly sulphide ore, although some oxidized material is found even on the lowest levels. Galena, chalcopyrite, and pyrite are the common sulphides, in a gangue of calcite, fluorite, and some quartz. Oxidation products are plumbojarosite, cerusite, cerargyrite, jarosite, malachite, wad, and "limonite."

The ore shipped in years just prior to the time of this survey averaged between 40 and 50 per cent of lead, with about 1 ounce of silver to 1 per cent of lead. Some carloads assayed as much as $3.50 a ton in gold, but in others the gold was insignificant. A few carloads carried paying quantities of copper, but there were no true copper ores.

CHLORIDE POINT

The Chloride Point mine is on the southeast flank of Silveropolis Hill at an elevation of about 8,150 feet. The mine is reached by wagon road from Ophir by way of Long Trail Gulch, a distance of about 2 miles. The road is very steep and tortuous.

Developments and production.—The mine is developed by means of two subparallel tunnels, following the ore. (See pl. 25.) The ore bodies are confined to shallow depths, and no deep winzes or inclines were necessary. The total development work probably does not exceed 5,000 feet.

The mine was one of the first discovered on Lion Hill, being located in August, 1870. The production of the mine was nearly all made in the early days, when bonanza lead-silver ores were found. In recent years lessees have produced a considerable quantity of ore but probably not approaching the output of the early miners. Under the circumstances an estimate of the total production is a mere guess, but certainly it exceeds $200,000 and may exceed $1,000,000.

Geology.—The mine is just east of the axis of the Ophir anticline, in the lower beds of the "Great Blue" limestone, a short distance beneath the Long Trail shale member. The limestone beds strike slightly west of north and dip 25°–35° E. They are little disturbed by faults in the neighborhood of the Chloride Point mine but are cut by north-south fissures, which doubtless governed the localization of the ore to a great extent. Two fissures about 20 feet apart have been followed for over 600 feet north from the portal, and very rich ore was found along them. Another fissure about 250 feet west of these was picked up and followed along its strike, about N. 10° E., for over 600 feet. Crosscuts about 350 feet northwest of the Gladstone shaft intersected the Gladstone fissure, which strikes N. 40° E. and dips about 80° NW. An incline 175 feet north of the Gladstone shaft follows one of the intermediate fissures down to the north and connects with the workings at the Buffalo mine, about 80 feet lower than the main tunnel of the Chloride Point mine.

Ore bodies.—The ore bodies of the mine were chiefly blanket and pipe deposits along the intersection of the fissures and just below or in the lower part of the jasperoid bodies. Presumably the ore was originally deposited in the jasperoid and owes its transfer to the beds immediately below to slight migration during oxidation. Some of the stopes were as much as 80 feet wide, but more commonly they were 10 or 15 feet wide and 3 to 8 feet high.

The ore is practically all oxidized and consists of cerusite, plumbojarosite, cerargyrite, malachite, jarosite, and "limonite." Silica, barite, and calcite are common gangue minerals. Subordinate minerals in this mine include aurichalcite, stibnite, stibiconite, and argentojarosite.

The tenor of the ores in recent years has averaged about 70 ounces of silver and $2 in gold to the ton, 8 per cent of lead, and a little copper. This is much lower than the tenor of the old bonanza ore, in which assays of hundreds of ounces of silver to the ton were common.

EAST SIDE, MONARCH, IRON, EMPIRE, NORTHERN LIGHT, AND WOODRUFF

The East Side, Monarch, Iron, Empire, Northern Light, and Woodruff mines, all of which were located and worked intensively in the early days of the district, are on the northeast and east sides of Lion Hill, near the crest of the hill. They are reached by wagon road from Ophir by way of Long Trail Gulch. Several thousand feet of development work was done, chiefly within 100 feet of the surface. The production was practically all made in the early days of the camp and ran to many thousands of dollars, but the total is unknown.

Geology.—The mines are all in the lower part of the "Great Blue" limestone, below the Long Trail shale member. The strata here are just east of the axis of

the Ophir anticline and dip at low angles to the east, with a generally north-south strike. The ore deposits, like those of the Chloride Point mine, occur in or closely associated with jasperoid. In part but not all of the workings the jasperoid lies immediately beneath a sill of "Birdseye" porphyry. Most of the old workings are now inaccessible, but the ore is known to have followed very irregular, generally northeasterly fissures in the jasperoid. It was chiefly in the form of pipes, but in the East Side tunnel and the Monarch group some large bedded replacement bodies were found. The workings are shown in Plate 25.

The ore was practically entirely oxidized and, if specimens examined on the old dumps are typical, consisted chiefly of cerusite, plumbojarosite, jarosite, cerargyrite, and wad. Butler [94] reports a yellow lead-arsenic mineral of undetermined composition from this group, but it was not noted during the present survey. A beautiful specimen of cerargyrite from the East Side tunnel was given to the writer by Mr. George St. Clair as typical of a large mass there found. It was of such purity that it could be sawed with an ordinary saw. According to Mr. St. Clair, assays as high as 6,000 ounces of silver and 3 ounces of gold to the ton were reported on the richest ore and large masses ran as much as 300 ounces of silver and $6 to $8 in gold to the ton. Assays showing as much as 35 per cent of lead were common.

At the time of this survey the Iron tunnel was under lease to James, William, and Patrick Kelly, who reported that the hand-picked ore they were producing in small lots ran from 60 to 100 ounces of silver and $1.50 to $3 in gold to the ton and from 14 to 20 per cent of lead.

LION, ZELLA, DOUGLAS, AND ADJACENT MINES

The Lion, Zella, Douglas, and adjacent mines are on the western and northern slopes of Lion Hill near the crest. They were vigorously worked in the early days of mining in the district but had been practically inactive for many years prior to the time of this survey, 1926 and 1927. The production of the group probably exceeded $1,000,000.

All these mines are in the lower part of the "Great Blue" limestone, where it dips gently westward on the western flank of the Ophir anticline. The ores are intimately associated with jasperoid. The workings of all these mines are now caved and inaccessible, and little can be added to the following description by Huntley: [95]

> The Zella group comprises the Zella, Mountain Tiger, Silver Chief, and Rockwell, patented, and several others unpatented. It is situated on the western side and near the summit of Lion Hill. * * * The ore outcropped in two places, the croppings assaying $200 per ton. Three large bodies and several smaller ones were found about 20 feet below the surface. The ore is a soft yellow siliceous chloride assaying several hundred dollars per ton. * * * The mines are opened by several shafts and tunnels, in all over 6,500 feet. The actual working development on the stratum containing ore does not, however, extend over 125 feet vertically and 800 feet horizontally. * * * The total product of this group was estimated at $750,000.
>
> The Douglas mine * * * is situated near the western summit of Lion Hill. * * * It is near the Monarch group, which it greatly resembles in gangue and ore. The country rock is stratified limestone. Whether the quartzite gouge of the Monarch is an interstratified quartzite bed or a local mass of quartzite can not be determined from the developments. [This "quartzite" is undoubtedly jasperoid, derived from limestone by silicification during ore deposition.] This stratum is 30 feet thick and is known to extend 250 by 350 feet. Two bodies have been found of about the same size 50 feet apart. One is 150 feet long, from 2 to 12 feet thick, and from 4 to 15 feet wide. The mine * * * is worked over 150 feet from the surface and has about 600 feet of cuttings. The total product is said to be at least 1,000 tons of 100-ounce ore.

The Lion mine is on the southwest slopes of Lion Hill, along a northward-trending fissure dipping west. The ore is associated with jasperoid. Huntley estimated the production as $120,000.

A fault trending N. 45° W. was observed at the Zella mine, and considerable work had been done along the contact of a lamprophyre dike, trending due north.

All these mines were dry and worked oxidized ores, presumably identical with those of the Chloride Point mine. The gangue was siliceous and sericitic, with barite and calcite. The ore was composed of cerargyrite, plumbojarosite, cerusite, and jarosite.

THREE METALS

The Three Metals tunnel, owned by the Ophir Metal Co., is in Long Trail Gulch, at an altitude of about 7,300 feet. It is reached by wagon road from Ophir, about a mile and a quarter away. The tunnel extends under Lion Hill a distance of nearly 2,000 feet. A few score tons of lead-silver ore was extracted, and the total production was only a few thousand dollars. The ore ran about $3 in gold and 90 ounces of silver to the ton, 11 per cent of lead, and a little copper.

The geology of the mine is simple, the tunnel being a crosscut, penetrating the lower part of the "Great Blue" limestone and the upper part of the Humbug formation. The beds strike generally N. 15°–50° W. and dip 12°–40° E., flattening toward the face of the tunnel as they approach the axis of the Ophir anticline. The fissures intersected in the tunnel all strike northeast. Most of them dip west, but one sheeted zone along which the tunnel is driven for about 300 feet near the portal, has a southward dip. (See fig. 17.) The attempt was made in this tunnel to prospect be-

[94] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 381, 1920.
[95] Huntley, D. B., Tenth Census U. S., vol. 13, p. 451, 1885.

neath the formerly productive "chloride" mines of Lion Hill, and for this reason, presumably, the course of the tunnel as a whole is about S. 40° W. The face of the tunnel is probably about vertically beneath the old Monarch workings.

FOOTHILL AREA

LAKES OF KILLARNEY

The Lakes of Killarney mine is in the western foothills of the Oquirrh Mountains, about a quarter of a mile south of the mouth of Dry Canyon. It is reached by wagon road from the loading station at the Bates ranch, on Ophir Creek, a distance of about 1½ miles. The mine was worked in the early days and is locally credited with a production approaching $250,000, but nothing is known to confirm or refute this report. Within the 20 years preceding the present survey only a few tons of silver ore were mined. Active prospecting was going forward at the time of this survey in 1927.

The principal developments of the mine are in two beds of limestone about 40 feet apart in the "Great Blue" limestone just below the Manning Canyon shale. There is a 3-foot shale overlying the upper bed and a somewhat thinner one above the lower. The old stopes are cut off on the west by a fault trending N. 30° W. and dipping 55° SW., parallel to the great Lakes of Killarney fault, 100 yards or so to the east.

The ore occurs in jasperoid breccia which replaces these limestone beds along fissures trending N. 10°–15° W., N. 20° W., and N. 50° W., all with steep east dips. Most of the workings are in the upper of the two beds. Considerable sericite and calcite occur in the jasperoid, but no ore minerals other than a little malachite were discernible.

According to James Quinn, superintendent, assays as high as 600 ounces of silver to the ton have been reported on the ore, but this is of course much higher than the mine run. The small amount of ore shipped in recent years averages just under 50 ounces of silver to the ton, with a little gold. Traces of lead and copper also occur but in far less than commercial limits.

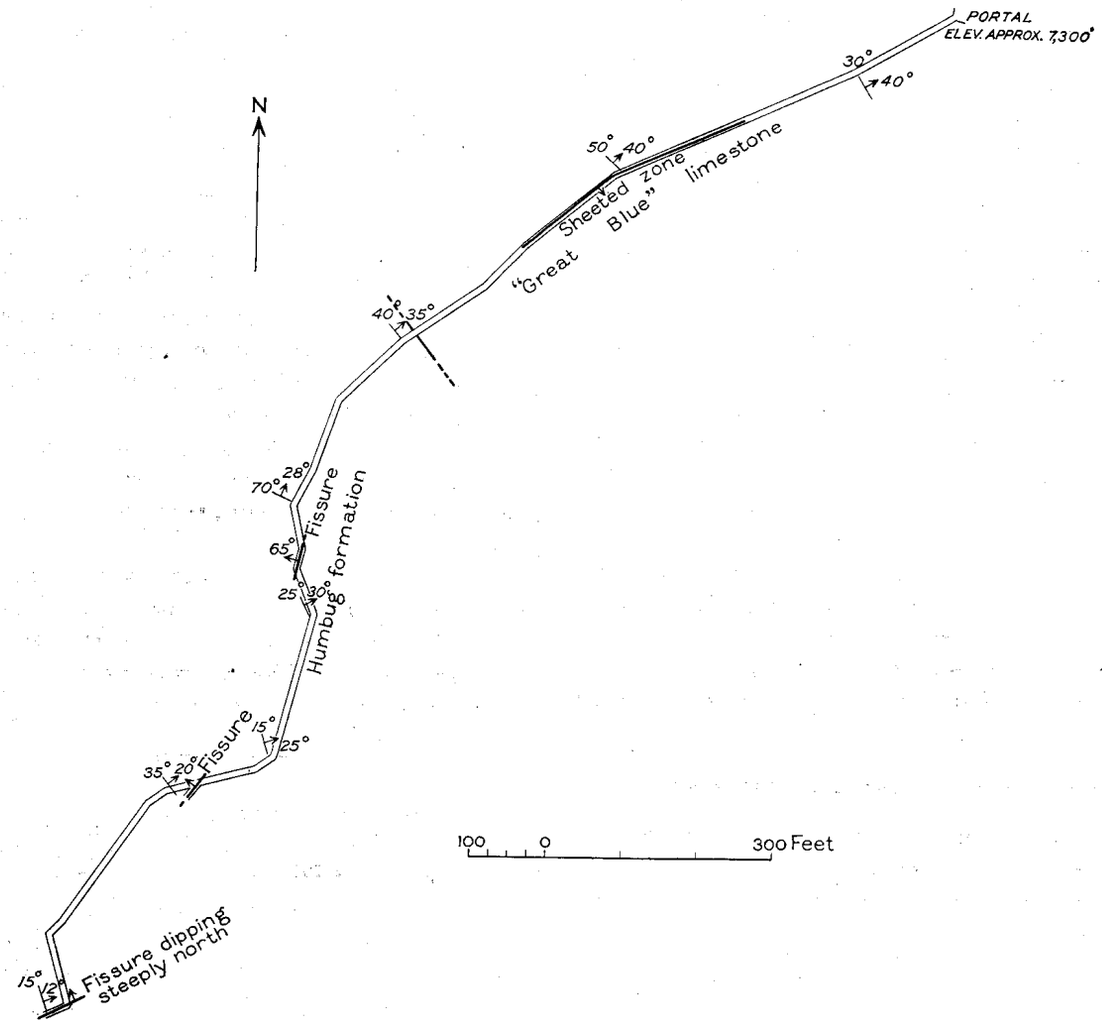


FIGURE 17.—Geologic map of the Three Metals tunnel, Ophir district

OPHIR HILL AREA

ADMIRAL DEWEY

The Admiral Dewey prospect is in Hartmann Gulch about half a mile north of the town of Ophir. The only developments at the property are a tunnel a few score feet long, an incline, and some surface trenches. The tunnel follows the contact of a 4-foot lamprophyre dike, which cuts the Bowman limestone a short distance above the base. An incline a short distance up the hill from the tunnel follows the intersection of a fissure and the bedding for about 150 feet. The fissure trends N. 15° E. and dips 70° NW. It contains a narrow vein of galena, with oxidation minerals including "limonite," jarosite, gypsum, and cerusite. A few sacks of high-grade ore have been produced from this prospect, but no development into a mine has been attempted.

CLIFF

Location.—The Cliff mine is on the north slope of Ophir Canyon about a mile northwest of Ophir and about 1,000 feet lower than the Dry Canyon divide. The mine is reached by a wagon road from Ophir. An aerial tramway, built about 1905, connects the mine with the railroad at Ophir. Before 1912 the ore was hauled from the foot of this tramway to St. John Station by tractor.

Development and production.—The mine was worked in the early days of the district but was dormant or only moderately active for a long period till 1905, when it was again actively worked for about 15 years. Since the World War there has been little production from the Cliff mine, but statistics of production since 1918 are combined with those of the Hidden Treasure mine, which is under the same ownership, so that definite information is not available. This property was for several years the largest producer in the district. The total production is unknown but is probably between $2,000,000 and $3,000,000. The property consists of several claims, of which the Buckhorn, Eighth of January, Trafalgar, Tomahawk, and Corning contain most of the workings.

The mine is developed by three tunnels along the Cliff fault, at altitudes of about 7,840, 8,060, and 8,260 feet. These tunnels are respectively 2,100, 1,450, and 800 feet long. From all of them main drifts have been run westward in the footwall of the Cliff fault—on the lower level about 700 feet, on the middle level about 1,600 feet, and on the upper level about 1,400 feet. With the minor drifts and crosscuts and the numerous winzes and raises, both in the Cliff fault and in the Madison limestone, the total openings of the mine amount to at least 12,000 feet. The mine is connected on the middle level with the Hidden Treasure mine and has been worked as a unit with that mine since 1918. At the time of the survey in 1926 and 1927 the property was under lease, as it had been for many years, to D. W. Lynch, of Salt Lake City.

Geology.—The workings of the Cliff mine are in the Lynch dolomite, the Jefferson (?) dolomite, and the lower beds of the Madison limestone, as well as in the Cliff fault between walls of these formations. (See pl. 27.) The lower adits penetrate the Lynch dolomite in the footwall of the Cliff fault. Practically all the replacement ore was confined to the Madison limestone, although locally the ore made down into the upper part of the Jefferson (?) dolomite. Most of the production within the Madison limestone has been derived from two beds, one at the base, the other about 40 feet higher. The lower part of the Madison limestone, including these beds, is locally called "Buckhorn" limestone. It is possible that some of the ore which was supposed to occur in the upper part of the Jefferson (?) dolomite (locally called the "Gray lime") was actually in the Madison, occupying sink holes in the upper surface of the Jefferson (?) dolomite, such as are illustrated in Figure 4.

The structure of the mine is relatively simple. The workings are practically confined to the footwall (northwest) side of the Cliff fault, which has here a total displacement of about 400 feet. Exact measurement is very difficult underground, owing to the multiple slicing along the fault, so that it is rarely certain that all branches of the fault have been penetrated in a given crosscut of the fault. The beds on both sides of the fault strike N. 50°–85° W. and dip about 20°–50° NE. The beds form a part of the eastern limb of the Ophir anticline.

The Cliff fault trends about N. 35°–40° E. and dips 60°–65° SE. It has been mined for 550 feet below the lowest level of the mine in some places and practically to the surface elsewhere, through a vertical distance of fully 1,100 feet. On the middle tunnel level the drift extending along the contact between Jefferson (?) dolomite and Madison limestone passes into the dolomite for several hundred feet (see pl. 27) and then penetrates a breccia mass consisting of mixed rhyolite porphyry fragments and dolomite and limestone. This breccia forms the hanging wall of a fault with probable downthrow of about 60 feet on the west, which strikes N. 45° E. and dips 60° W. at the drift but curves to a nearly east-west strike within about 300 feet to the northeast. This contact as well as the overlying porphyry-limestone breccia has been mineralized, and stopes of rather large dimensions have been opened above and below this level. A winze has been sunk on the fault about 80 feet south of the drift. The hanging wall of this porphyry breccia has been explored in the Hidden Treasure workings but without success. The same prophyry is cut by the

drift from the upper adit of the mine. The drift penetrates the porphyry, which is about 75 feet thick, and a crosscut is carried south into the dolomite footwall for about 100 feet.

Ore bodies.—The principal ore bodies of the mine were replacement masses along fissures in the Madison limestone and replacement and fissure ores in the Cliff fault. The ores in the limestone footwall of the Cliff fault were localized along rather inconspicuous fissures, of which the four largest strike N. 40°–55° E. and most dip very steeply east. On the upper tunnel level these four fissures are cut by the drift along the basal Madison beds at 50, 250, 400, and 650 feet west of the Cliff fault. The fissures are rather irregular, and minor fissures run out from them in many directions. The ore bodies were not very large. Some exceeded 100 feet in strike length along the bedding, but few were more than 1 or 2 feet thick. More common dimensions were 12 feet wide by 6 feet high. Their continuation in depth was irregular, only two shoots continuing to the lower tunnel level. Several stopes were about 60 to 100 feet long. The limestone walls of the stopes are very vuggy and open and show strong oxidation stains even on the lower tunnel level.

The ore bodies in the Cliff fault zone were largely tabular deposits replacing dolomite and limestone blocks between the several branches of the fault, although there was undoubtedly some fissure filling also. On the level of the middle tunnel the Cliff fault is composed, near the portal, of three principal branches forming a fault zone about 60 feet wide, which narrows as the three branches unite, about 1,000 feet in. On the lower level the zone is about 40 feet wide, and on the upper level there are several branches which unite and separate as they are followed in strike. Similar branching and reunion of the faults occur in dip as well. The ore is localized along these faults and replaces the sliced rock between them. Apparently the dolomite and limestone were equally susceptible to this replacement, as some large ore bodies occur well below any limestone slices. Some of the ore bodies were 60 to 80 feet long and 12 feet wide. The largest stopes appear to have been in the faults to the east of the principal (footwall) fault of the Cliff zone. Large masses of carbonate occur in these faults, some lining caves. Despite the free circulation of water along these fissures much of the fault zone ore was unoxidized, even on the upper level.

The ores.—The bedded replacement ores of the Cliff mine were largely oxidized ores of lead and silver, carrying paying quantities of copper and gold as subordinate constituents. Oxidation occurred to the deepest levels explored, but sulphide residua were common almost to the surface. The principal hypogene minerals were pyrite, galena, sphalerite, and chalcopyrite. On oxidation, cerusite, plumbojarosite, smithsonite, malachite, aurichalcite, and azurite were the common products, with jarosite and various oxides of iron. Only a small quantity of oxidized zinc ore was mined from the Cliff property, although such ores were conspicuous in the Hidden Treasure mine. The only conspicuous gangue mineral is manganiferous calcite, but very small quantities of silicates and quartz also occur.

The ore from the Cliff fault zone was much less thoroughly oxidized than the bedded replacement ore. It was composed of the same hypogene minerals but was accompanied by considerable silicate gangue, chiefly diopside, andradite, epidote, and tremolite. It is quite evident that the Cliff fault was one of the principal channels through which the mineralizing solutions gained access to the rocks.

The tenor of the ore was such that it was all shipped direct to the smelter without milling. The average tenor for several years before the World War was lead about 13 to 15 per cent, copper a little less than 1 per cent, silver about 8 ounces to the ton, and gold about 25 cents to the ton. A little zinc ore was also shipped about this time, but its tenor is unknown.

HIDDEN TREASURE, CHICAGO, AND SACRAMENTO

Location and accessibility.—The Hidden Treasure, Chicago, and Sacramento are three of the most famous mines of the early days of Utah mining. They are on the Ophir side of the divide, between Dry and Ophir Canyons, just below the crest. In the early days they were worked through inclines from the outcrop on the divide and were reached by a circuitous road from Dry Canyon, but since the driving of the Sovereign adit tunnel, from the bed of Dry Canyon, which intersects the workings of all three at depth, they have been worked through this adit. The ore from the Cliff mine is also shipped through the Sovereign tunnel. The mine is reached by wagon road up Dry Canyon from the Bates ranch. The ore is hauled by team to a siding at the Bates ranch, a distance of 3½ miles.

In the early days the mines were independent properties, but after the rich bonanzas had been extracted they were combined into one holding, which since 1918 has included the Cliff mine. All are now worked as a unit. Living quarters for the miners are maintained at the Cliff portal. The principal claims included in the property are the Hidden Treasure amended, Columbia, Chicago No. 2, Sacramento, Red Pine, Anna, Summit, and Hercules. For many years the property has been under lease to D. W. Lynch, formerly with associates.

Development and production.—The mines were developed in the early days by sinking inclines either in

the ore shoots or closely alongside them. These inclines are now largely caved near the surface, but at least five are known to have extended for fully 1,800 feet in dip length. The Granite tunnel was driven from the hillside south of Dry Canyon at an altitude about 220 feet below the portal of the old Hidden Treasure incline, and from it an incline was sunk between the two main ore shoots. This is known as the Hidden Treasure main incline and was the chief haulageway of the mine for many years. The Sovereign tunnel, 450 feet lower than the Granite tunnel, was connected with all the workings and has since been the main working entry. Including all the tunnels and inclines, the development work in the mines probably exceeds 15,000 feet. (See pl. 27.)

The mines have been among the largest producers in the district. In the early days they were wholly lead-silver mines and found very rich bonanza ore at the surface. Long after this easily accessible ore was exhausted, the presence of oxidized zinc ores occurring as sheaths about the old stopes was recognized, and the mine yielded largely in zinc. The production data for the early days are very uncertain, but it is probably safe to attribute to these mines a total production of over $3,000,000 in lead, silver, zinc, copper, and gold.

Geology.—The Chicago, Hidden Treasure, and Sacramento mines are all in the Madison limestone. The Hidden Treasure ore shoots were, in general, in the upper beds of the Madison, but the ore only exceptionally occurred in the very topmost beds, just beneath the basal phosphatic shale member of the Deseret limestone. A foot or two of barren limestone intervened along most of the length of the ore bodies. The Chicago and Sacramento ore bodies showed practically no tendency to be limited to a single stratigraphic horizon but passed up and down through the section as they were followed, although both were in the Madison limestone throughout.

These mines are close to the axis of the Ophir anticline, where the strata strike N. 70°–80° E. and dip 30°–35° N. The attitude of the beds is surprisingly regular, being broken only by very insignificant faults and slightly exaggerated dips.

Only three noteworthy faults were observed in the workings. A steeply northward-dipping fault trending N. 60° E. along the tenth level of the Hidden Treasure mine has a displacement of 15 or 20 feet down on the north. A fault striking N. 40° E. and dipping steeply southeast cuts the Hidden Treasure incline about 80 feet south of the Sovereign drift and is also a normal fault of about 30 feet displacement. A fault striking N. 15° W. and dipping 75° SW. just east of the porphyry breccia mass which separates the Hidden Treasure group from the Cliff workings on the Sovereign level probably has no great displacement, as no notable offset is to be seen on the surface, and the relations of the Madison limestone and Jefferson(?) dolomite on the Sovereign level hardly permit appreciable displacement.

The structural features that have had an important effect on the ore deposits are the fissures. These all stand essentially vertical and although irregular in detail, form rather well-marked zones which trend generally within 5° or 10° of north. They show little or no displacement. The ore bodies of the mines are all localized along these fissures.

Ore bodies.—The upper workings of the mines are all caved and inaccessible. According to Mr. Lynch, who has long been familiar with the mines, there were five principal ore shoots—the Hidden Treasure east side and west side shoots, the Chicago east side and west side stopes, and the Sacramento.

The ore bodies forming the Hidden Treasure shoots cropped out together, just beneath the basal shale of the Deseret limestone. Almost immediately below the surface the ore shoot split in two parts, which diverged northward until they were about 300 feet apart. These are known as the east side and west side stopes. The ore made along these fissure systems, chiefly within less than 100 feet stratigraphically below the basal phosphatic shale of the Deseret limestone. The ore bodies were in some places fully 100 feet high and as much as 50 feet wide. Where they were as wide as this they were generally due to several subparallel fissures rather than to a single one. The ore bodies formed pipes rather than blanket replacement deposits, not being confined to a single bed or even a single group of beds. Toward the north the shoots dropped stratigraphically lower, though nowhere as far in the Hidden Treasure mine as in the Sacramento.

The fissures are in large part enlarged into open caves as much as 100 feet high, lined with crystalline calcite. The west side stopes were not so large as the east side. Where the west side stopes trend easterly, about halfway between the Granite tunnel and the Sovereign tunnel, a number of short branching fissures pass out into the northwest wall of the ore body but pinch out in a short distance.

The Chicago ore was entirely in pipes, following fissures without regard to any particular bed. At the outcrop the main ore shoot was about 200 feet stratigraphically below the Hidden Treasure, on the same fissures. Like the Hidden Treasure this shoot split down the dip into an east branch and a west branch, of which the east one was the larger, as in the Hidden Treasure. These branches at first pitched into lower beds but farther north were deflected upward and finally joined the Hidden Treasure shoots. The Chicago ore shoots were as much as 10 to 15 feet high

and 8 to 10 feet wide. Locally there were two or more pipelike masses, one above another on the same fissure. Such shoots branched and rejoined as they followed the fissures but showed no regard for any stratigraphic horizon.

The Sacramento shoot cropped out about 600 feet east of the Hidden Treasure, close to the contact of a prominent rhyolite porphyry dike and the upper beds of the Madison limestone. The ore body was pipelike in shape and followed fissures that trend slightly west of north and do not appear to have any regular relation to the rhyolite intrusion. When followed northward the ore shoot was found to descend stratigraphically until it was fully 300 feet below the top of the Madison limestone, although at the surface it was immediately below the basal shale of the Deseret limestone. The Sacramento shoot has been followed to a depth of 400 feet below the Sovereign tunnel level, a vertical distance of about 1,100 feet.

The ores.—The dominant ore of these mines has from the first been oxidized lead-silver ore, even to the greatest depths attained. Pockets of unoxidized galena and sphalerite were found almost at the surface, however, and are the chief constituents of the ore for as much as 400 feet above the Sovereign tunnel level on the few tight fissures. At no time have sulphide ores been the principal product of the mines.

The hypogene ore consisted essentially of pyrite, galena (carrying argentite), sphalerite, and chalcopyrite, the minerals varying greatly in relative quantity from place to place. On the whole, galena was the dominant sulphide, but locally sphalerite predominated. These minerals were deposited with a gangue of silicates, of which wollastonite, sericite, epidote, actinolite, adularia, diopside, and a little chlorite, tremolite, and andradite were most abundant. Quartz also accompanied the ore, and probably some topaz and marialite were present as well. The chert nodules that are so prominent in the upper part of the Madison limestone commonly show alteration to radiating masses of wollastonite and quartz. Considerable apatite also occurs in the ore, but in view of the large amount of accompanying collophane it is possibly due to recrystallization of material derived from the overlying phosphatic shale bed at the base of the Deseret limestone.

Despite the large number of silicates found in the gangue, the limestone appears megascopically to be but little altered and effervesces freely with dilute acid. Microscopic examination is required to show the extent of metamorphism it has undergone. Much residual calcite, of course, remains, and the metamorphism has been not nearly so intense as that in the Ophir Hill mine, for example.

The hypogene sulphides have been oxidized, with the production of cerusite, plumbojarosite, horn silver, malachite, azurite, cuprite, aurichalcite, smithsonite, hydrozincite, calamine, zinc-bearing clay, limonite, and wad. The zinc carbonate ores have been described by Loughlin.[96] Of the oxidized minerals cerusite and plumbojarosite were the most abundant. Ferruginous smithsonite was the chief zinc mineral, and malachite and azurite the chief copper minerals. Lead carbonate formed the mass of the stopes. Locally this was partly surrounded by a thin casing of malachite-azurite ore. The lead and copper shoots were in general partly inclosed by a layer of smithsonite, chiefly in the footwalls of the stopes. This smithsonite layer was only exceptionally over 6 inches thick, but owing to its high grade and the ease of its extraction from the old lead stopes, in which at first it had not been recognized, it was very profitable.

The ore mined in the early days ran from 15 to 40 ounces of silver to the ton and 20 to 50 per cent of lead. According to Mr. Lynch, in the period just preceding this survey, the lead carbonate ore which has been the chief ore of the mine averaged 21 to 22 per cent of lead, with a maximum of 40 per cent. Silver averaged 18 or 19 ounces to the ton, zinc 4 to 6 per cent after sorting out, and iron 22 per cent. The zinc carbonate ores ran 40 per cent of zinc on an average, with a maximum of 44 per cent in carload lots. This zinc ore carries an average of 1 per cent of copper and about 2 ounces of silver to the ton. The copper carbonate ores ran about 22 per cent of copper.

The sulphides, which have been mined only in recent years, average about 30 per cent of zinc, 14 per cent of lead, and 8 or 10 ounces of silver to the ton. As much as 50 cents in gold to the ton may occur in any of the ores, but it is not consistent.

JIM FISK

The Jim Fisk mine is in Jim Fisk Gulch, a small gulch on the north wall of Ophir Canyon, about half a mile northeast of Ophir, at an altitude of about 7,200 feet. The site of the old Baltic mill, which served this mine in the early days, is at the junction of Jim Fisk Gulch and Ophir Canyon, about 600 feet lower than the lower tunnel of the old mine.

The mine is developed by two principal drifts, 900 and 300 feet long, with some smaller drifts and inclines and raises connecting them, both lower and higher than the principal drifts. Mining has been carried out through a vertical distance of over 600 feet, how extensively the writer is unable to say, because much of the mine was inaccessible at the time

[96] Loughlin, G. F., Zinc carbonate and related ores at Ophir, Utah: U. S. Geol. Survey Bull. 690, pp. 1–14, 1919.

of the survey, in 1927. A map of the workings kindly furnished by Mr. J. Fewson Smith, of the United States Smelting, Refining & Mining Co., is reproduced in Figure 18.

The mine was opened in the early days and was vigorously exploited at that time. It has been operated at intervals since, chiefly by lessees; the last work prior to this survey was done by J. F. Worthing in 1923. After the field work on this report was completed, in 1928, work was renewed on the Jim Fisk, but no information has been obtained as to the nature of this development or its results. The total output of the mine is unknown. It is estimated locally at about $500,000, but this is probably excessive, and $200,000 would probably be nearer the correct total.

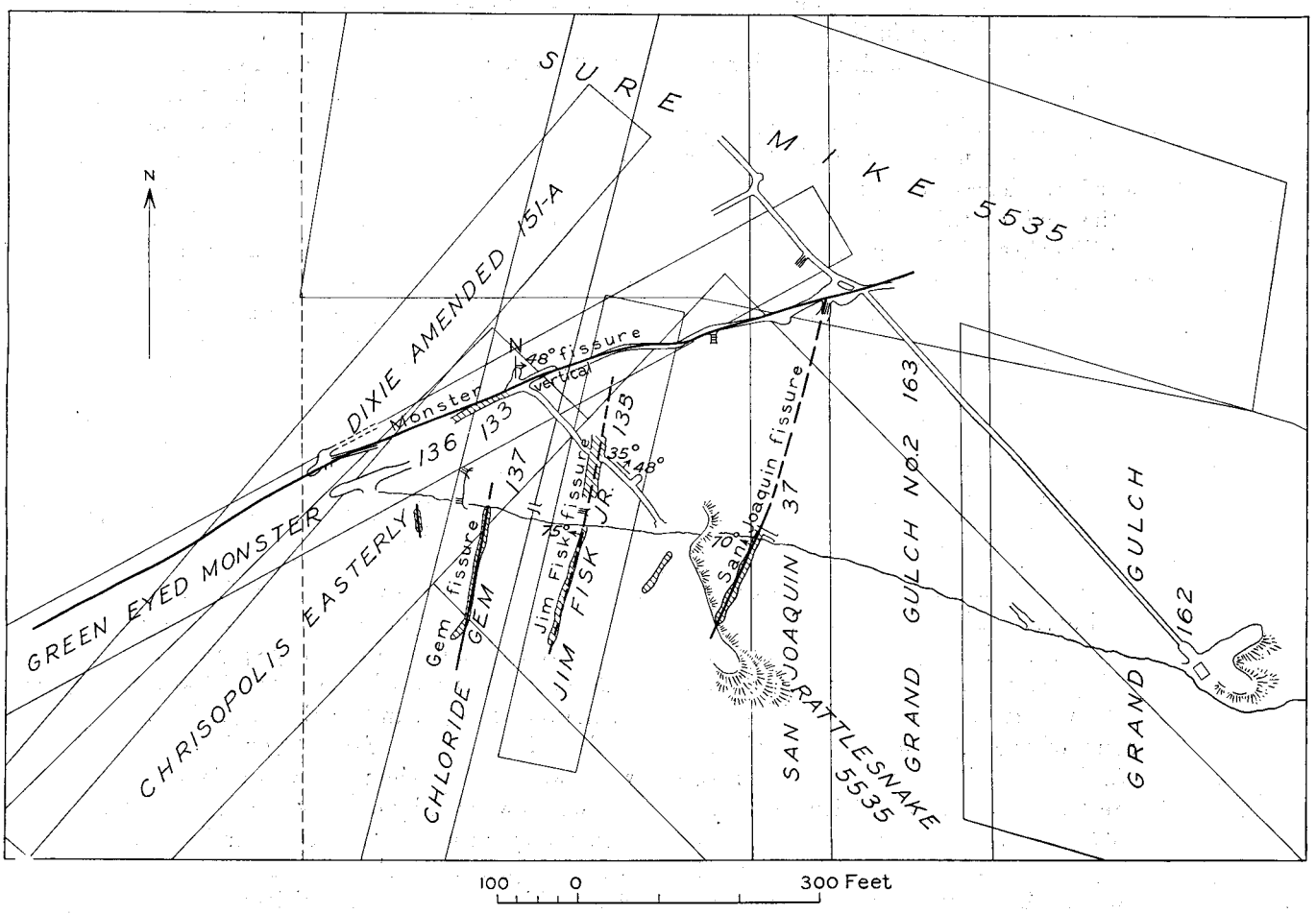


FIGURE 18.—Map of the workings of the Jim Fisk mine, Ophir district

Geology.—The workings of the Jim Fisk mine are in the uppermost beds of the Madison limestone and the lowest beds of the Deseret limestone. The beds dip 45°–50° E. on the east flank of the Ophir anticline. The general strike is about N. 35°–40° W.

The beds are cut by a number of fissures that strike N. 10°–30° E. and dip steeply northwest and by the Green Eyed Monster fissure, a fault fissure of slight displacement, which strikes N. 75° E. and stands nearly vertical. Just south of this fault fissure the beds strike N. 35° W.; just north of it they strike due north. The ore of the mine was found chiefly along the Green Eyed Monster and three of the N. 10°–30° E. fissures—the Gem, Jim Fisk, and San Joaquin. Some of the ore was fissure filling, but most of it had replaced the limestone, both above and below the basal shale of the Deseret limestone. Stopes 6 feet high and 4 feet wide along the Jim Fisk fissure were opened on the upper tunnel level. This fissure was mined for about 250 feet. The stopes along the Green Eyed Monster fissure were both above and below the shale and are about 30 feet high where the mine was accessible. They plunge parallel to the dip of the beds. They were mined for a width of 8 feet in places and averaged perhaps 5 feet.

No ore samples could be obtained at the time of the visit to the mine in 1927, but according to Mr. George St. Clair, who was connected with the mine when it was in operation, the ore consisted of native silver, ruby silver, "antimonial silver," horn silver, a little lead carbonate, and probably argentite. The ore was oxidized, as is evident from this list of minerals. The ore ran as much as several hundred ounces of silver

to the ton and carried a little copper and lead as well as a few cents in gold to the ton.

OPHIR COALITION (MONTANA)

The Ophir Coalition group is on the north wall of Ophir Canyon, about half a mile north of Ophir, just west of the workings of the Ophir Hill Consolidated mine. The group consists of about 12 claims, of which the Lost Boy, Teller, and Montana have thus far proved the most productive.

The mine is developed by means of a vertical shaft about 500 feet deep, with inclines in the limestones of the Ophir formation. Litigation with the Ophir Hill Consolidated Mining Co. resulted in a decision in favor of that company, to which the more productive part of the workings, developed through the Montana shaft, were awarded. These workings formed the Clark stope of the Ophir Hill. The geology of the Montana mine is like that of the Ophir Hill Consolidated and requires no discussion, as there has been no development other than that in the Ophir formation.

OPHIR HILL CONSOLIDATED

Location.—The Ophir Hill Consolidated mine is about a quarter of a mile northwest of Ophir, and the working adit and drain tunnel are in the north wall of Ophir Canyon just west of the town.

Development and production.—The properties of the Ophir Hill Consolidated mine include a consolidation of many claims, of which the Wild Delirium, Miner's Delight, Bartlett, Northern Light, Bannock, Burnett, Cooley, Severe, Maud S., Our Boy's, and First Northerly Extension of the Miner's Delight have so far proved most valuable.

The development of the mine was first carried out by inclined shafts in the ore, but in 1911 a drain tunnel about 2,400 feet long was driven, with an altitude at the portal of 6,502 feet. Considerable drifting was done on the drain-tunnel level and on the 200 and 400 foot levels below it. All together more than 10,000 feet of drifts and tunnels have been driven, with many raises and a few winzes, and the stope workings must be of even greater length. The water in the mine stands at the level of the drain tunnel. No information was obtained as to its natural level before the completion of this drain.

The production of the mine began about 1870. The mine was idle for many years in the period between 1880 and 1897, but work was resumed then and continued until 1926, when the mine was abandoned, being considered exhausted. During this period over 1,200,000 tons of ore was produced, and the value of the output must have exceeded $15,000,000 and may have approached $20,000,000. The ownership of the stock has been so closely held that no information as to dividend payments is available, but it is known that the mine has been very profitable, especially from a time shortly after 1900 to the cessation of operations while under the ownership of the W. A. Clark interests.

Geology.—The productive workings of the Ophir Hill Consolidated mine are all confined to the Ophir formation and almost entirely to a few limestone beds of the formation. (See pl. 28.) The most consistently mineralized limestone is that known as the "Copper vein" limestone. It is about 8 feet thick and is about 110 feet above the base of the formation. Just below the "Copper vein" limestone and separated from it only by 1½ to 2 feet of shale is the "Blue vein" limestone, about 6 feet thick. This is also consistently ore bearing and is commonly mined in one stope with the "Copper vein." About 25 feet above the "Copper vein" limestone and separated from it by barren shale is a 10 to 14 foot limestone known as the "Middle vein" limestone. This in turn is separated by 25 feet of shale from the "Big vein" limestone, which ranges from 20 to 40 feet in thickness. A 2-foot shale parting divides the "Big vein" limestone from the "Top vein" limestone. Still higher, at the top of the formation, is a 5 to 8 foot limestone to which no name has been given. This bed is also locally altered to ore.

The "Copper vein" limestone, with its close associate the "Blue vein" limestone, is most widely replaced and has furnished the largest ore bodies of the mine. The "Middle vein" and "Big vein" limestones are less consistently ore bearing, and ore bodies in the "Top vein" limestone are only sporadic.

Almost all the workable ores of the mine occurred in the block of ground in the angle between the Cliff fault and the Canyon fault. Considerable exploratory work was done on the northwest side of the Cliff fault but was rewarded by only very meager discoveries. It seems very probable that the localization of the ore was due primarily to the shattering of this wedge-shaped block during the faulting.

In this wedge-shaped block the strata strike N. 60°–75° W. and dip 15°–25° NE., forming part of the northeast limb of the Ophir anticline. The attitude of the rocks is very regular except close to the Cliff fault, where there is a great deal of drag and much slicing of the rock into horses of large and small size.

There are few faults of any consequence except the Cliff fault and its branches. A nearly vertical fault called the Big fault, with a downthrow to the north of 40 feet, cuts the "Copper vein" about 300 feet down the dip from the outcrop in the Wild Delirium stope. This fault curves from a course about N. 70° E. to about N. 55° E. and also cuts the Miner's Delight stopes at about 300 feet down the dip from the outcrop. A number of steep faults having throws as great

as 5 feet also occur in the mine. They strike generally east, and all but one also show downthrows to the north, like the Big fault. The ore bodies cropped out a short distance north of the Canyon fault. The ore occurred in blanketlike replacement masses along a series of roughly northward-trending fissures, following the intersection of the fissures with the several favorable limestone beds. There were also very large stopes in the sliced rocks in the Cliff fault zone and in the hanging wall of the Cliff fault.

The stopes along the Cliff fault extend for over 2,000 feet, though not continuously mined for this distance. The very rich Clark stope was developed at the west end of this zone in the "Copper vein" in the hanging wall of the Cliff fault. A large ore body was found in the "Middle vein" above and west of the Clark stope, and a smaller stope was developed in the "Big vein."

Along the Cliff fault to the northeast the Senator stope was developed in a horse of the "Big vein," and from this point a practically continuous series of stopes were developed to the northeast along the plunging intersection of the limestones of the Ophir formation and the Cliff fault. Many of these ore bodies were in horses in the fault zone, and their proper description would require a detailed map, permission to publish which was not received.

Of the ore bodies localized along fissures, the most westerly was the West stope. This was developed, with some small interruptions, for over 500 feet from the intersection of the "Copper vein" with the Cliff fault. It trends from due north to N. 75° W. The principal stope was in the "Copper vein" and was locally 50 feet wide but probably averaged less than 15 feet. The "Middle vein" stopes were not so persistent nor so wide, and the "Big vein" was mined for only about 200 feet along the fissure. None of the ore bodies along this fissure system extended to the surface. A branch of the West stope fissure system trends easterly, and the stope along it in the "Copper vein" connected with the "Copper vein" stope along the Miner's Delight fissure system, some 150 to 200 feet east. Two other small ore bodies were found along fissures between the West stope and the Miner's Delight.

The Miner's Delight fissure system trends almost due north and has been mined for a pitch length of 1,450 feet from the outcrop, practically to the intersection of the "Copper vein" with the Cliff fault. Ore bodies in all the beds were very good, the "Copper vein" stopes averaging about 40 feet in width, the "Middle vein" about 10 feet, the "Big vein" about 40 feet, and the "Top vein" being more continuously productive along this fissure system than anywhere else in the mine, some of the stopes in it being 80 feet wide.

A few small ore bodies occur along minor fissure systems 100 to 150 feet east of the Miner's Delight system, but they were not continuous, although one stope over 300 feet long was developed in the "Copper vein" south of the Cliff fault.

The next major fissure system east of the Miner's Delight was the Wild Delirium, which extends in a course about 300 feet east of and subparallel with the Miner's Delight fissure system. It controlled the largest and most valuable deposits in the mine. The ore bodies extended from the outcrop to the Cliff fault in the "Copper vein," about 1,500 feet in pitch length, and were only slightly less continuous in the "Middle vein" and "Big vein" limestones. Except near the outcrop no valuable ore bodies were found in the "Top vein" limestone. The ore body in the "Copper vein" limestone was 90 feet wide for several hundred feet along its pitch, but near the surface, owing to a branching of the fissures, it attained a width of 120 feet. These branching fissures near the outcrop showed some continuation down the dip about 200 feet east of the Wild Delirium fissures proper, producing the ore body mined in the Peterson stope, a continuation of the very rich Bonanza stope just below the outcrop. Caving had rendered this portion of the mine inaccessible at the time of this survey, so that the mutual relations of the fissures could not be ascertained.

In the "Middle vein" and "Big vein" limestones the stopes along the Wild Delirium fissure system were very wide near the surface, exceeding 100 feet for short distances, but were very much narrower down the dip to the north, averaging 20 to 30 and 10 feet, respectively, in width.

The 7½ drift was run in the "Copper vein" limestone east from the Wild Delirium stopes at the drain-tunnel level and revealed ore bodies along two fissure systems. One fissure about 250 feet east of the Wild Delirium localized ore bodies that were minable for about 500 feet in the "Copper vein" and for about 100 feet in the "Middle vein" limestone. The other system, about 120 feet farther east, localized ore bodies that were mined for over 600 feet in the "Copper vein" and nearly as far in the "Middle vein" and "Big vein." None of these ore bodies cropped out.

A few smaller ore bodies were found east of the Wild Delirium system, practically along the Cliff fault at and below the 200-foot level below the drain tunnel.

Extensive explorations were made on the northwest side of the Cliff fault, chiefly in the "Copper vein," which was followed for about 800 feet on the drain-tunnel level, about 300 feet on the 200-foot level, and over 1,700 feet on the 400-foot level, but only two very small ore bodies were found. The "Big vein" was

explored on the 200-foot level for about 1,200 feet of strike length northwest of the Cliff fault without success and on the drain-tunnel level for a short distance, where a small ore body was found. Explorations in the lower beds of the Hartmann limestone northwest of the Cliff fault on the tunnel level were fruitless.

Essentially all the fissures along which the ore bodies were localized are nearly vertical, with perhaps slight westward inclinations. They are surprisingly inconspicuous, considering the great size of some of the ore bodies. Commonly the fissures are 2 to 3 inches wide, but locally they attain about 4 inches and elsewhere shrink to mere knife-edges. As a rule there are several such fissures in a zone as much as 4 feet wide, within which they are found to join and separate continually when followed along the stope roof. Despite their narrow width and the additional facts that they sharply cut the replacement ore that made most of the ore bodies of the mine, and furthermore, although almost without galena or sphalerite, carry much more pyrrhotite, chalcopyrite, and tennantite than the replacement ore, their central positions in the stopes and their never-failing presence are conclusive evidence of their genetic relations to the replacement ore. They are traceable in the shale between the ore bodies as well as in the shale and quartzite below the "Blue vein" limestone where the workings have extended.

On reaching the conclusion that the Ophir Hill Consolidated mine on the north side of the Canyon fault was exhausted, the company began search for another ore body south of this fault. If the Canyon fault had been postmineral, they would have been practically assured of success, but the evidence of a premineral age of this fault is almost conclusive, rendering the results of exploration by deep shaft south of the fault much more uncertain. After diamond drilling had revealed some pyrite in limestone of the Ophir formation south of the Canyon fault, a winze from the end of a 300-foot tunnel in the south wall of Ophir Canyon was begun in 1926 and carried to a depth of about 1,400 feet. Drifts were run in the Tintic quartzite in search of fissures and also in the "Copper" vein limestone of the Ophir formation, but without result. The work was abandoned in 1928.

Evidence of the premineral age of the faulting may be summarized as follows: First, the practical absence of ore northwest of the Cliff fault would hardly be expected were this fault postmineral. Second, the fraying out into northeastward-bending "horsetails" of almost all the mineralized fissures just south of the Cliff fault suggests that the fault was earlier than the fissures. Third, the mineralized limestones in the Cliff fault zone show no evidence of drag. Fourth, the Cliff fault has clearly localized metamorphism on the hillside between the Ophir Hill and Cliff mines and hence is premineral. Fifth, vugs in the Cliff fault zone contain anhedral pyrite and galena, which also occur in the fault gouge, although no broken crystals are seen there. The Cliff fault appears to be a branch of the Canyon fault. (See p. 75.) Sixth, the mineralized fissures show no offsets where they cross the small faults that are parallel to the Canyon fault, and these small faults are mineralized well away from any limestone beds, proving their premineral age. Their parallelism to the Canyon fault suggests that they are of the same age as the Canyon fault, which hence is also premineral. Seventh, the Canyon fault carries quartz-pyrite filling locally, as above the Ophir Hill mill. Eighth, the rhyolite dike that crosses the Canyon and Cliff faults without offset and is clearly later than these faults has been mineralized in the Hidden Treasure mine. Ninth, the manganese mine of the Ophir Hill Consolidated Co. follows a fissure system that is parallel to and only a few score feet from the Canyon fault. The manganese (introduced as manganiferous calcite) was almost surely formed at the same time as the lead and zinc minerals, which were hence later than the Canyon fault.

Some of the evidences above enumerated are not strong, but others are nearly conclusive in themselves, and all suggest the same conclusion—namely, that the Cliff and Canyon faults are both premineral. Accordingly this conclusion carries considerably greater weight than it would have from any single line of evidence.

The conclusion drawn from the evidence just cited is directly contrary to that of Olmstead[97] and Wichman,[98] neither of whom states the reasons for his conclusion. The exploratory work carried out by the Ophir Hill Consolidated Co. south of the Canyon fault apparently confirms the evidence that the mineralization occurred later than the faulting.

Twelve carloads of manganese ore was mined during the World War by the Ophir Hill Consolidated Co. from the Bowman limestone, just south of the Canyon fault on the spur between Hartmann Gulch and the gulch in which the easterly outcrop of Tintic quartzite occurs. The ore was all oxidized, consisting of pyrolusite, psilomelane, and wad, undoubtedly secondary after manganiferous calcite. The ore was localized in the hanging wall and along branches of a fissure that trends due east and dips 80° N. The limestone has been replaced through a vertical distance of about 60 feet and locally to distances of 6 to 8 feet to the side of the fissures. Certain limestone beds appear

[97] Olmstead, S. G., Economic geology of the Ophir mining district: Econ. Geology, vol. 16, p. 447, 1921.

[98] Wichman, F. M., The Ophir mining district, Utah: Eng. and Min. Jour. vol. 110, p. 562, 1920.

to have been selectively replaced, leaving nodular limestone residua convex toward the fissures, but on the whole the irregular minor fractures that abound in the rock have guided the replacement. Mining was done by the room and pillar method.

The ores.—The ore of the main Ophir Hill mine was composed of mixed pyrite, galena, sphalerite, and chalcopyrite, with some argentite occurring in the galena and some tennantite and pyrrhotite as minor constituents. The gangue was extremely variable, ranging from nearly all silicate to fairly pure limestone with only a small percentage of insoluble matter. The insoluble matter in the ore ranged from 13 to 92 per cent. This made selective flotation very difficult, owing to the variable effects of the changes in lime content of the mill heads.

The metal contents did not vary systematically from one bed to another nor from one fissure to another, although there were considerable fluctuations in the relative proportions of the several metallic minerals within any given ore body.

The tenor was rather low except near the outcrop of the Miner's Delight and Wild Delirium fissure systems, where oxidation had produced very rich lead carbonate and silver ore. This did not extend more than 75 feet down the dip, according to Mr. E. S. Bowman, of the Ophir Hill Consolidated Mining Co. Along the Cliff fault oxidation occurred to much greater depth, supergene chalcocite being found on the Miner's Delight level, about 25 feet above the drain tunnel. The average of the ore mined in the later years of activity ran about 1.3 per cent of copper, 5.5 to 6 per cent of lead, 6 to 7 ounces of silver to the ton, 4 to 8 per cent of zinc, 12 per cent of iron, and 42 per cent of insoluble material. The gold content was insignificant. The lime content of mill heads averaged about 8 per cent. Most of the ore was milling ore, but some ran 12 to 15 per cent of lead, 2 per cent of copper, and 15 ounces of silver to the ton and was shipped as mined. A little copper ore, running 4 to 5 per cent of copper, 3 per cent of lead, and 15 ounces of silver to the ton, was also shipped. In general, high copper was accompanied by high silver content and very low lead. The maximum contents reported on carload lots were 15 ounces of silver to the ton, 15 per cent of lead, 10 per cent of zinc, and 30 per cent of iron. The small amount of manganese mined ran 47 to 48 per cent of manganese and 1 ounce of silver to the ton.

Until 1921 the ore was milled by straight gravity concentration with jigs and tables, but in that year the jigs and fine tables were eliminated and replaced by flotation. In 1924 the tables were also eliminated and flotation was used alone, with about 30 per cent better recovery of copper and about 10 per cent better recovery of lead and silver. The tailings losses were copper 0.096 per cent, lead 0.5 per cent, silver 0.6 ounce to the ton. The extraction, according to R. V. Thompson, mill superintendent, was about 90 per cent of the copper, 91 per cent of the silver, 93 per cent of the lead, 55 per cent of the iron, 67 per cent of the zinc, 8 per cent of the silica, and 8 per cent of the lime contained in the mill heads. The concentration was about 2.5 to 1, and the concentrates ran, when the process was standardized, about 20 to 30 per cent of lead, 4 per cent of copper, 30 to 40 ounces of silver to the ton, and 7 or 8 per cent of iron.

OPHIR QUEEN

The Ophir Queen prospect is in Hartmann Gulch a few hundred feet north of the Ophir schoolhouse, just north of the northern branch of the Canyon fault.

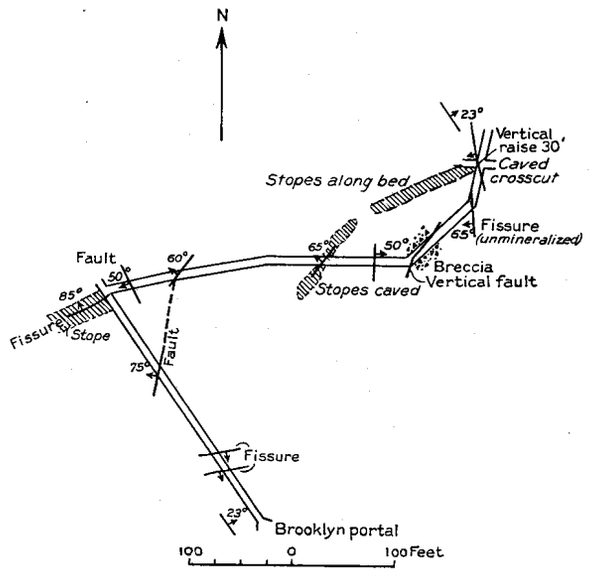


FIGURE 19.—Map of the accessible workings of the Brooklyn mine, Dry Canyon

A shaft was sunk here about 250 feet, and a small amount of drifting was done in the limestone of the Ophir formation. No production was ever reported, and the shaft was abandoned at the time of the survey in 1926.

DRY CANYON AREA

BROOKLYN

The Brooklyn mine is in Dry Canyon about a quarter of a mile north of the Kearsarge. It was discovered in the early days of the district, and most of the work was done at that time. No data on the early production are available. Less than 1,000 tons of ore was extracted at about the time of the World War, but the mine was inactive at the time of the writer's visit, and most of the workings were caved and inaccessible. The accessible portions, amounting to about 1,000 feet, are shown on Figure 19. From the small amount of workings visible it is difficult to say

what conditions governed the ore bodies. They appear, however, to have been chiefly replacement pods and masses in the limestone of the "Great Blue," just above the Long Trail shale member. Many faults and fissures cut the beds and confuse the structure somewhat, but in general the beds strike N. 35° W. and dip 20°–25° NE., in conformity with their position on the east flank of the Ophir anticline. There appear to have been at least two beds that were productive, one about 130 to 140 feet stratigraphically higher than the other. In some places fissures seem to have localized the ore, but other stopes reveal no fissuring.

The ore was apparently all oxidized and contained lead, silver, and copper. The average tenor of the ore mined since 1910 would be about 11 per cent of lead, 4 per cent of copper, and 6 ounces of silver, and about $1.30 in gold to the ton.

COMMODORE

The Commodore mine is on the southeast flank of Bald Mountain, northeast of the Brooklyn mine, in Dry Canyon. It is in the "Great Blue" limestone above the Long Trail shale member. As the workings were caved and inaccessible at the time of this survey in 1927, nothing is known of the geology of the ore bodies. A small amount of ore was mined in the decade preceding 1918, but the total production was probably less than $10,000, chiefly in lead and silver ore, with a little copper and gold.

DESERET

The Deseret mine is on the north wall of Dry Canyon on the spur below the Kearsarge mine. It was worked in the early days, but has long been idle. Its total production has been only a few thousand dollars.

The mine is developed by an incline parallel to the bedding and about 750 feet deep, with a few short drifts and some small stopes parallel to the incline. Altogether about 1,500 feet of workings have been opened.

The mine is in the Deseret limestone, near the top. The beds here strike almost due east and dip about 35° N. at the surface, but flatten to 15° at lower levels. The limestone in which most of the workings of the mine were driven is considerably altered to hornfels, especially along the fissures, which trend generally north through the mine. It is overlain by a quartzite that is similarly altered, with the development of diopside. The ore is reported by Huntley[1] to have occurred as a chimney deposit, following the bedding. It assayed 70 ounces of silver and a trace of gold to the ton.

[1] Huntley, D. B., Tenth Census U. S., vol. 13, p. 454.

EUREKA-OPHIR

The Eureka-Ophir mine is in Dry Canyon just east of the portal of the Sovereign tunnel of the Hidden Treasure mine. It was worked sporadically from about 1913 to 1921 and at the time of the writer's visit was under lease, but little was being done. Nothing is known of its earlier history.

The mine is opened by an inclined shaft about 300 feet deep, which was badly caved at the time of the visit. The mine is in a brecciated mass of Deseret limestone and rhyolite porphyry, chiefly above the basal shale of the Deseret. The workings that penetrate below this shale give no evidence of having ever been productive, despite the fact that all the production of the adjacent Hidden Treasure mine came from beds below this shale. There is much fissuring of the breccia above the shale, but very little below. The ore apparently made along these fissures, which trend generally north. The ore was oxidized throughout. It averaged about 6 per cent of lead, 6 per cent of copper, and 9 ounces of silver and 25 cents in gold to the ton.

KEARSARGE

The Kearsarge mine is in Dry Canyon on the spur east of the old Mono incline, about 150 feet above the road to the Granite tunnel of the Hidden Treasure mine. It is reached by wagon road from Stockton, about 7 miles.

The mine is developed by an incline subparallel to the bedding and about 1,300 feet long, and at the time of the writer's visit a tunnel about 450 feet long and about 200 feet below the main adit was under way to prospect the ground beneath the Callahan stope. With the few short levels in the mine, the total development work is probably about 3,000 feet.

Despite the small amount of workings in the mine it has proved very productive. It was first located in 1871, and its output to 1880 was reported as probably about $1,000,000.[2] Since that time work has been very sporadic and done chiefly by lessees operating on a small scale. A small production has been reported up to the present time, but the total output since 1911 probably does not exceed 1,000 tons of ore.

The workings of the mine (see fig. 20) are somewhat above the middle of the Humbug formation. The beds here form a part of the east limb of the Ophir anticline but locally strike a little north of east and dip about 30°–35° N. The beds are cut by a number of fissures trending N. 30°–60° E., most of which dip steeply east without marked offset of the beds, although they are accompanied by considerable brecciation. A small northwest fault is cut by the incline about 700 feet down, and a few small northeast faults also occur in the workings.

[2] Huntley, D. B., op. cit., p. 453, 1885.

The ore occurred as fissure fillings and replacement masses in the brecciated quartzite and limestone of the Humbug formation. Some alteration to hornfels has occurred along the limestones, but there has been little replacement of them by ore. The richest ore body was in the Callahan stope between quartzite walls. The ore bodies were not confined to any particular stratigraphic horizon, although there is a crude tendency for them to be subparallel to the bedding. The ore was chiefly oxidized ore, although some sulphides were found in the Callahan stope and at lower levels.

The mine is in the "Great Blue" limestone just below the Long Trail shale member, in beds apparently equivalent to those in which the Mono mine was developed. The writer was denied access to the property, so that nothing can be stated regarding the shape and size of the ore bodies. It is known, however, that little ore has been so far developed.

MONO

The Mono mine, a part of the Ophir-Mono coalition, is on the north side of Dry Canyon about half a mile from Gisborn post office. It is reached by the Gisborn road from Stockton, about 6 miles distant.

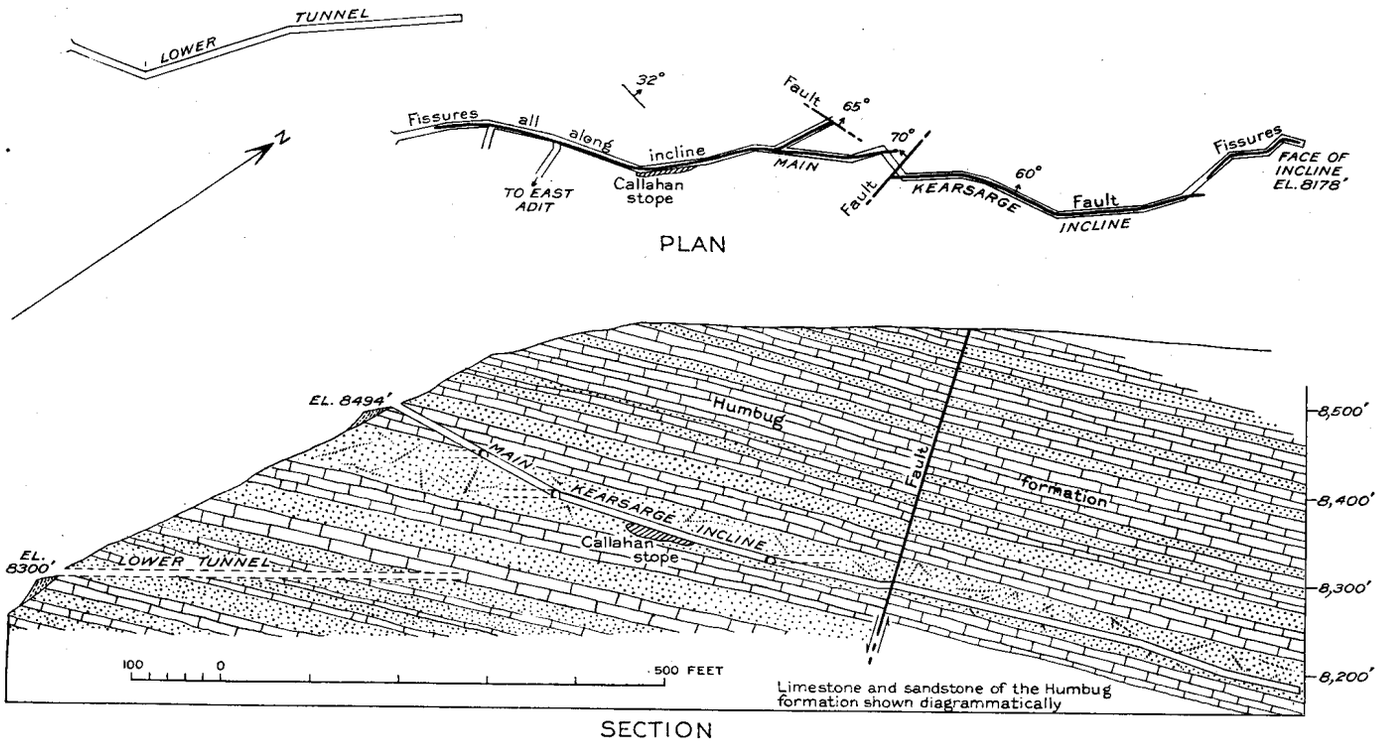


FIGURE 20.—Map and section of the Kearsarge mine workings, Dry Canyon

Jarosite, smithsonite, azurite, malachite, aurichalcite, plumbojarosite, and "limonite" were seen in the mine and on the dumps, with a little galena.

The tenor of the ore mined in the early days was very high, some assays reaching $10,000 a ton in silver. The ore mined by lessees in recent years has been, of course, much poorer. It averages about 7 per cent of lead, 2 per cent of copper, and 18 ounces of silver and about $1.25 in gold to the ton.

MAGNOLIA

The Magnolia mine is on the north wall of Dry Canyon a few hundred feet west of the upper portal of the Mono mine. A tunnel is driven beneath the upper workings from a point about 300 feet lower. A great deal of exploratory work was done here in the early days, but the total production is reported by Huntley to have been small. Within the last decade a few score tons of ore has been extracted.

Developments and production.—The Mono mine is developed by means of an incline whose mouth is at an altitude of about 8,450 feet and which follows the dip of the strata for several hundred feet. This incline was worked in the early days but was largely caved at the time of this survey in 1927, and its depth is not known. A short tunnel, about 650 feet long, was driven at an altitude about 150 feet lower, and a longer one at about 450 feet below the collar of the incline, beginning just above the bed of Dry Canyon. It was extended over 1,100 feet before 1880, but soon afterward work was abandoned, and except for a few lessees little work was done until 1927. Under the direction of M. C. Godbe work was resumed under the name Ophir-Mono Coalition, which includes the properties known as the Surprise tunnel, Queen of the Hills, and several others as well. The Mono lower

tunnel was being rapidly extended at the time of the writer's visit to the mine, and there were at least 3,200 feet of workings on the lower tunnel level.

The production of the mine was very great in the early days, close to $1,000,000 being produced in the years between 1871 and 1875. Since then work has been done only sporadically, and the production has probably not exceeded $100,000.

Geology.—The Mono mine is in the Deseret limestone, Humbug formation, and "Great Blue" limestone, but essentially all the productive workings are in a 3 or 4 foot limestone bed in the "Great Blue" limestone about 190 feet beneath the Long Trail shale member, according to the detailed work of H. G. Mitchell, superintendent. It thus roughly corresponds in stratigraphic position with the Lion Hill and Mercur mines.

The mine is in a downfaulted block, bounded on the east by the Corbon fault and on the west by the Garber-Mark Antony fault. The Corbon fault is well exposed in the lower tunnel of the mine, the portal of which is in the footwall of the fault. The principal fault surface where it is cut by the tunnel about 150 feet from the portal (see pl. 29) strikes N. 25° E. and dips 30° NW. The tunnel passes into the hanging wall of the fault for some distance but swings back and again intersects the fault about 2,000 feet from the portal. Here the fault strikes N. 20° E. and dips 48° NW.

The Corbon fault where followed southwest from the portal curves westward and then turns northwest, becoming one with the Garber-Mark Antony fault. (See pl. 11.) The wedge-shaped block between them includes the Mono mine. These faults are described in detail on pages 78–80. Their apparent displacement is about 650 feet and 750 feet, respectively. Within the block defined by these faults the strata dip generally about 30°–40° NE. and strike N. 30°–55° W., forming part of the east limb of the Ophir anticline. They are cut by many northeastward-trending faults, chiefly of small displacement, though of great economic importance, as the bonanza shoot of the old Mono incline is reported to have been cut off by such a fault.

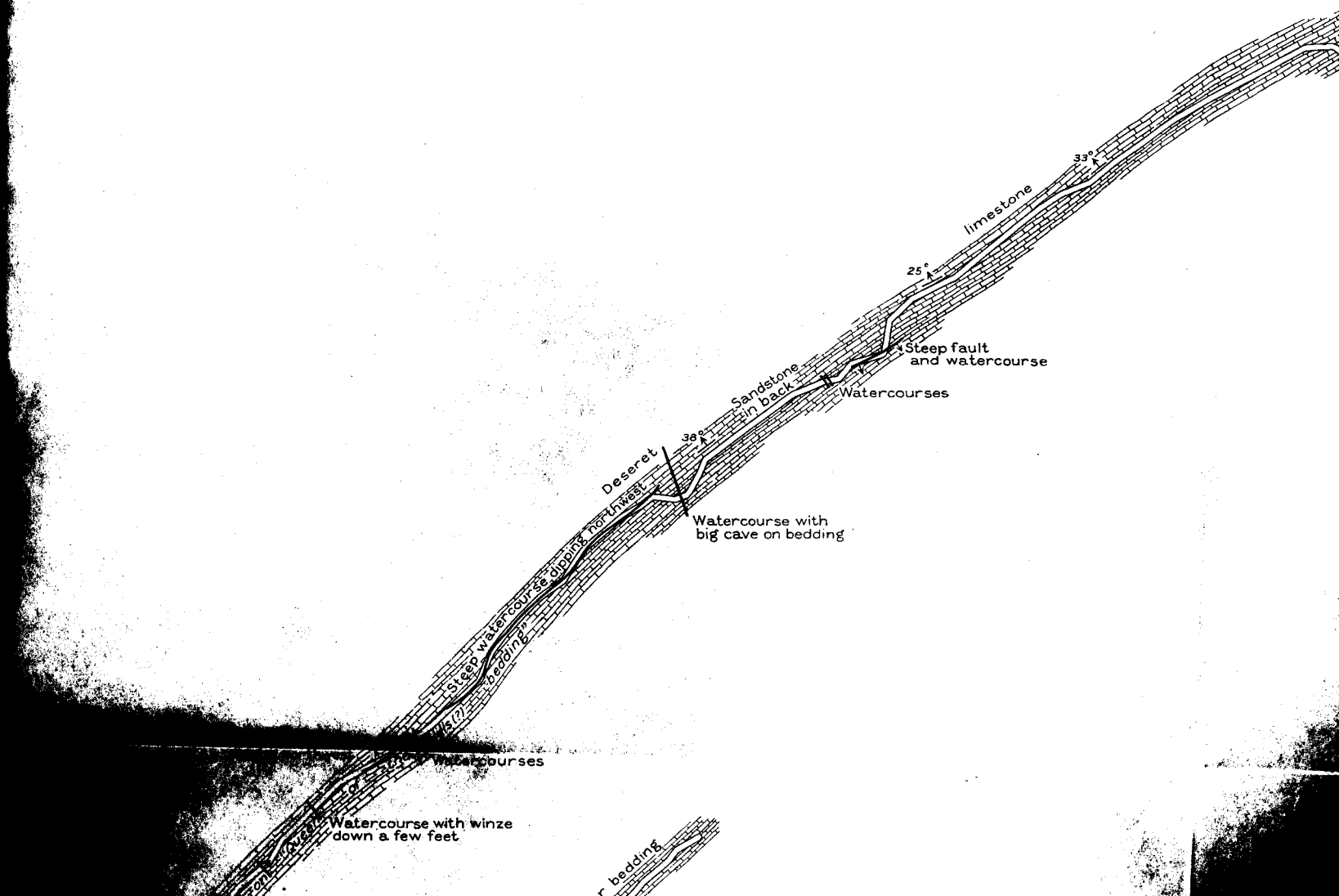
The upper Mono incline of the mine follows down the intersection of a fissure that trends N. 5° E. and a limestone bed that strikes about N. 50° W. and dips 28° NE. The ore made out into the limestone as replacement masses as much as 30 feet wide and 3 or 4 feet thick. About 350 feet down the incline this ore shoot was cut off by a fault trending N. 45° E. with a steep dip to the northwest. The fault is apparently normal and has a throw approaching 200 feet, for a black shale that is almost surely the Long Trail shale member of the "Great Blue" limestone is dropped opposite the ore-bearing bed. These relations are exhibited by the workings accessible through the upper tunnel of the mine.

The upper tunnel penetrates for nearly 200 feet from the portal a mass of rhyolite porphyry, which is much pyritized. The porphyry mass is then cut off by a fault trending N. 15° E. and dipping 75° NW. Beyond this the tunnel cuts across the strike of the "Great Blue" limestone at a low angle for several hundred feet, finally passing under the incline. Apparently no attempt was made to prospect the favorable limestone of the ore shoot along its strike.

The lower tunnel passes through a breccia zone of Deseret limestone for about 150 feet, then through the Corbon No. 1 fault, into what is probably the uppermost part of the Deseret limestone in the hanging wall of the fault. These beds it penetrates at a low angle with the strike for a little over 200 feet and then cuts a fault, of probably slight displacement, trending N. 30° E. and dipping 80° NW. The Humbug formation, striking N. 40° W. and dipping 27° NE., is encountered in the hanging wall of this fault and is penetrated, through slightly broken country, for a little over 600 feet. Here the tunnel forks, one branch extending on north-northeastward through the Humbug formation and finally intersecting the Corbon No. 1 fault again. Along this tunnel a few small ore bodies following narrow fissures were stoped. The largest of these was a peculiar curving body dipping at a flat angle northward just south of a steep fault. Apparently this branch of the tunnel fails to reach the "Great Blue" limestone, although it must be very nearly through the Humbug where it strikes the Corbon fault for the second time. This fault is penetrated, and stopes are developed in a steeply dipping fault zone in its footwall. This footwall fault zone, which strikes N. 40° E. and dips 45° SE., has been mined for 60 or 80 feet below the tunnel level along about 200 feet in strike. The ore body was apparently about 3 to 5 feet wide.

The northwest branch of the tunnel was being actively advanced at the time of this survey. From the fork of the tunnel it follows the strike of the Humbug formation for about 150 feet, then a small northward-trending fault for a short distance, then the strike again. About 350 feet from the fork it penetrates a N. 60° E. fault dipping 60° NW., and a short distance farther on a very strong fault with parallel strike but somewhat flatter dip (46°). North of this flat fault the drift is in the "Great Blue" limestone and at the time of this survey was being extended southwestward to intersect the limestone bed that was so productive in the upper workings.

The ore in the upper workings of the Mono mine was oxidized, consisting of lead carbonate, horn silver, malachite, jarosite, azurite, and "limonite." On the


limestone
33°
25°
Steep fault
and watercourse
Sandstone
in back
Watercourses
38°
Deseret
Watercourse with
big cave on bedding
Steep watercourse dipping northwest
bedding
Watercourses
Watercourse with winze
down a few feet

lower tunnel level it was chiefly sphalerite, galena, pyrite, and chalcopyrite in a gangue of lime silicate rocks. There was little alteration in the upper workings away from the ore bodies proper.

The tenor of ore in the early days must have been very high, but no data are available. The ore shipped since 1910 averaged about 17 per cent of lead, 3.6 per cent of copper, and 16 ounces of silver and $1 in gold to the ton.

QUEEN OF THE HILLS

The Queen of the Hills mine is in Dry Canyon, in the southward-facing spur at whose crest is mineral monument No. 5. It is about a quarter of a mile from Gisborn and is reached by wagon road from Stockton, about 6½ miles away. The mine was located in 1870 and vigorously worked till 1877, but since that time a little desultory work by lessees has been the sole activity. In 1915 and 1916 considerable zinc ore was shipped. The mine is now owned by the Ophir-Mono Coalition. The production of the mine in the early days probably exceeded $1,000,000, but it is doubtful whether more than $30,000 has been recovered in the last 20 years.

The mine is in the Deseret limestone, about 100 feet below the base of the Humbug formation, although there is a quartzite immediately overlying the productive limestone of the mine which might be considered the basal member of the Humbug. The ore made along the intersection of three fissures with the bedding of the limestone. The limestone strikes almost due east and dips about 20°–25° N. The fissures trend about N. 20°–35° W. and are reported to have been cut off in depth by two faults, one of which is supposed to be a branch of the Mark Antony fault, the other a northeastward-trending fault. The ore shoots were not found on the north side of these faults.

Huntley [3] says:

> The dip of the chimneys is N. 30° W., being oblique to the dip of the strata. The distance between them is about 80 feet and 150 feet. Two faults were found, one along the line of the Mahogany chimney, northeast and southwest, and the other nearly at right angles to it, faulting all the ore shoots and dipping a little northeast. * * * The first chimney was 350 feet long (before being cut by the fault) and was from 25 to 40 feet wide, having a thickness of from 18 inches to 2 feet of ocherous ore containing but little copper and said to assay from 20 to 25 ounces silver and 50 per cent lead. The second chimney was 1,000 feet long, from 60 to 70 feet wide, and also had from 18 inches to 2 feet of ore, generally upon the hanging wall, assaying about 40 ounces silver and 30 per cent lead. The third chimney was about the same size as the second, but the ore contained some tetrahedrite, much malachite, and a little lead and assayed about 60 ounces silver. The claims are opened by two main inclines 1,000 and 1,400 feet long and 6 feet square, which branch near the surface like the letter Y. The horizontal development is 1,200 feet. It is claimed that there are 8 miles of openings, but if the stopes were not counted there would probably be not over 12,000 feet.

The stopes of the mine were reported by Mr. A. J. May to be practically all caved, although the haulageways are still partly accessible. The purpose of the Surprise tunnel (see below) is in part to explore for the faulted continuation of the ore shoots of the Queen of the Hills.

The ore shipped in recent years has averaged about 19 per cent of zinc, 6 per cent of lead, 1.4 per cent of copper, and 7 ounces of silver and 30 cents in gold to the ton.

SURPRISE

The Surprise tunnel, now a part of the Ophir-Mono coalition workings, is at Gisborn post office, on the west flank of the southwest spur of Bald Mountain. It is reached by wagon road from Stockton, about 6 miles distant. There has been a great deal of work done through the Surprise tunnel, including at the time of the survey, in 1927, about 4,200 feet of tunnel and over 500 feet of raises, but very little ore had been developed. The production has been only a few score tons, shipped in 1916, 1918, and 1920, the total value probably not reaching $10,000.

The tunnel is in the upper part of the Deseret limestone and in the Humbug formation. The beds form a part of the west limb of the Ophir anticline and, near the portal, strike about N. 50° E. and dip about 25°–40° NW. The tunnel begins as a crosscut trending S. 70° E. Three drifts have been driven to the northeast, one at 200 feet from the portal, a second at 550 feet, and the third at 720 feet. (See pl. 29.) The drift that leaves the crosscut at 720 feet from the portal is short and somewhat tortuous, subparallel to the strike of the Deseret limestone. No evidence of mineralization was observed along it, although a northwest fault that intersects the crosscut at the mouth of the drift has been prospected for a short distance and carries small quantities of sulphides. The drift that leaves the crosscut at 550 feet from the portal trends N. 50° E. along the strike of a bed in the Deseret limestone, locally called the "Garber" limestone. The drift is about 450 feet long and intersects two mineralized fissures, both nearly vertical. The first has been followed by a raise about 80 feet long along the intersection with the "Garber" bed, which here dips about 40° NW. The second has been prospected by a winze about 100 feet below the tunnel and a raise about 400 feet long above it. The small amount of ore yet produced by the tunnel was obtained from this raise.

The principal prospecting work from this tunnel was carried out along the drift that leaves the adit crosscut at 200 feet from the portal. This has been driven northeast for about 1,700 feet at about the same

[3] Huntley, D. B., Tenth Census U. S., vol. 13, p. 453, 1885.

stratigraphic horizon. The limestone followed by this drift is considered by the men in charge to be probably the same as the one in which the Queen of the Hills mine was developed. Like the Queen of the Hills bed, it has a quartzite overlying it, but talus prevents verifying by surface tracing the probable correlation of the beds. Both beds are considered by the writer part of the Deseret limestone, despite the presence of the quartzite, which might be included in the Humbug formation. The base of the Humbug is a purely arbitrary boundary, but as the quartzite here considered is several scores of feet lower than the principal group of sandrocks it is included as part of the Deseret limestone of the present report.

Open fissures, "watercourses," both parallel and crosscutting this drift, are encountered for much of its length. These are not mineralized. About 1,700 feet from the adit crosscut this drift intersects the Mark Antony fault, a strong fault trending about N. 45° W. and dipping 70°–75° NE. The fault relations are those of a normal fault, with the Humbug formation in the hanging wall brought down against the Deseret limestone. The Mark Antony and Garber faults are subparallel and really are the dominant surfaces of movement on a sheer zone about 200 feet wide on this tunnel level. After penetrating the Mark Antony fault the tunnel turns southeast, in the hanging wall, which is formed by the Humbug formation. A second fault of the zone is penetrated about 250 feet farther on, and the tunnel is again in the Deseret formation for a short distance. It then turns back southward to the main Mark Antony fault, which it follows for over 400 feet, with Deseret limestone on both hanging wall and footwall. A branch of this tunnel leaves the fault and passes into the footwall for over 200 feet, where drifts were being run both east and west in a limestone bed that must be low in the Deseret formation. A second drift leaves the fault and trends northeast till it penetrates the Garber fault, which it follows for several hundred feet, with the Humbug formation on the hanging wall and the Deseret limestone on the footwall. The Big Four raise was extended vertically up from a crosscut in the footwall, cutting the fault about 90 feet above the tunnel. A drift was being run from this raise at 115 feet above the tunnel at the time of the writer's visit. No evidence of mineralization was found in any of these workings.

The ores that were obtained from the small bodies in the Garber raise were chalcopyrite-galena ores with a little gold and considerable silver. The average tenor was 13 per cent of lead, 4 per cent of copper, and 28 ounces of silver and about 30 cents in gold to the ton.

THAD STEVENS

The Thad Stevens mine is in Dry Canyon just above the creek bottom northeast of the Eureka-Ophir mine and southeast of the Deseret. It is in one of a group of overlapping claims, which also includes the Deseret mine.

The mine was worked in the 1870's but had been operated in only a desultory way in the 20 years preceding 1927. The total production in the early days was estimated by Huntley[4] at less than $30,000; since 1910 it has surely not exceeded $10,000 additional.

The mine is in the Deseret limestone, which here strikes about N. 60° W. and dips about 25° N. The mine was caved and the workings inaccessible at the time of this survey, in 1927, so that details of the geology can not be given. Huntley described the mine in 1880 as having a 380-foot incline and about 250 feet of drifts. The ore was in chimney form, averaging about a foot in width, and averaged 35 per cent of lead and 30 ounces of silver to the ton. The ore produced in recent years assays about 10 per cent of lead, 4 per cent of copper, and 13 ounces of silver and 40 cents in gold to the ton.

UTAH QUEEN

The Utah Queen mine is on the north wall of Dry Canyon on the first spur west of the Mono mine. It was located and worked vigorously in the early days, and a large amount of ore was extracted, but the value of the output is unknown. In the 20-year period preceding this survey the mine was worked in only a desultory fashion, with the extraction of about 200 tons of ore, probably not exceeding $6,000 in value. The ore averaged about 11 per cent of lead, 2 per cent of copper, and 20 ounces of silver and 60 cents in gold to the ton.

The mine is in the Humbug formation, near the upper contact. The workings were caved and inaccessible at the time of this survey, and the mode of occurrence of the ore can not be stated. Presumably the mine resembled the Kearsarge, which is located in similar beds. Huntley[5] reports about 900 feet of workings in the mine in 1880.

RUSH VALLEY DISTRICT

STOCKTON AREA

ARGENT

The Argent mine is the most easterly in the Rush Valley district, being situated in sec. 20, T. 4 S., R. 4 W., about half a mile east of the Galena King mine. The Argent is one of the oldest mines in the district and was actively worked in the early days, but except

[4] Huntley, D. B., op. cit., p. 454.
[5] Idem., p. 454.

for occasional activity by lessees in a small way, it has been abandoned for many years. The mine is developed by a shaft reported to be 850 feet deep, but owing to the destruction of ladders below 300 feet the lower works were not accessible to the writer. Little drifting appears to have been done on the upper levels.

The mine is in the "Galena King" limestone, in the Oquirrh formation. The beds strike about N. 65° W. and dip about 70° NE. The ore appears to have occurred in two shoots along the Galena King gouge. These shoots pitch to the northwest, with the intersection of the limestone and two fissures of the north-south system. The stopes appear to have been rather large, having lengths as great as 60 feet.

The ore was apparently nearly all oxidized, but a few remnants of pyrite and galena were seen. The oxidized ores carried jarosite, plumbojarosite, cerusite, and "limonite." Nothing is known of the tenor of the ore.

BEN HARRISON

The Ben Harrison mine is in the northeastern part of the Rush Valley district, high in the gulch to which it has given its name. It is reached by a very steep wagon road from Stockton, a distance of about 3 miles. The mine was located in the early days of the camp and has been operated rather steadily for a long time, first as the Ben Harrison, then as the New Stockton. At the time of this survey it was being operated by lessees under the Combined Metals Reduction Co.

The mine is developed by means of a vertical shaft 1,000 feet deep, from which levels are turned at 200, 500, 700, 850, and 1,000 feet. (See fig. 21.) Drifts are run on all these levels and long crosscuts on the 500 and 700 levels. All together the development workings of the mine aggregate over 9,000 feet. Statistics of the early production of the mine are not available, but it probably produced at least $500,000 in the two decades preceding this survey, in 1927.

The mine is in the Oquirrh formation about 7,500 to 8,000 feet above the base. This part of the formation consists of quartzite and subordinate limestone beds. Two limestone beds constitute the principal sources of ore. These are the "Ben Harrison" limestone, about 40 feet thick, and the "Black Bear" limestone, about 80 feet thick. They are separated by approximately 190 feet of quartzite in the normal sequence, but owing to the gradational contact at the top of the "Ben Harrison" limestone, which ranges from limestone to quartzite through an interval of limy sandstone, as well as to the possible presence of some strike faults, the measurement is uncertain.

The beds strike about N. 80° E. and are essentially vertical or even overturned with south dips of 70°. There has been considerable strike faulting, probably during the folding, so that the apparent stratigraphic interval between the "Ben Harrison" and "Black Bear" limestones in the mine ranges from only 120 feet to nearly 200 feet. Besides the strike faults there are a number of north-south faults and fissures. Most of these dip very steeply west, but there are a few eastward-dipping fissures. Two prominent monzonite porphyry dikes were encountered in the mine. Both strike almost due north and dip about 60° W. The east dike ranges in thickness from 30 to 60 feet and on the 200-foot level is split in two. The west dike is less than 30 feet thick where intersected by mine workings. These dikes are considerably sheared by later faulting, and in many places their contacts are fault surfaces, but the regularity of their positions in the mine seems to indicate that these faults are chiefly subparallel to the dike walls and occasion but slight offset of them. In addition to the north-south fissures there are a number of fissures trending between N. 20° E. and N. 50° E. These show little displacement but are mineralized.

The ore bodies in the mine were confined chiefly to the "Ben Harrison" and "Black Bear" limestones, but there were some bodies along fissures in the quartzite, notably above the 700-foot level about 200 feet south of the "Ben Harrison" limestone drift. The ore bodies are localized by the fissures and as a rule dip steeply west, with the intersection of the fissures and the limestones. The fissure which has localized the largest ore bodies is the one called the Katherine, because it is supposed to be the northward continuation of the fissure known by that name in the Honerine mine. It is impossible, however, to verify the continuity of the fissure from the Honerine, which is over half a mile to the south. This fissure lies parallel to the east poryphyry dike, for the most part in the hanging wall, but where ore occurs in the footwall it, too, is referred to the Katherine fissure. It is probable that the brecciation along the dike has facilitated mineralization in both walls. There are two fissures west of the Katherine which also carry ore. These have received no names. The more important ore bodies are along the one which lies about 100 feet west of the shaft on the 700-foot level and is almost vertical below that but flattens slightly above and is only about 15 feet west of the shaft on the 200-foot level.

The ore bodies of the mine have not been very large. They are only locally as much as 30 feet long in the plane of the bedding and 10 feet wide. Their pitch length is variable, some exceeding 600 feet and others reaching only a few feet or scores of feet.

The hypogene ore consisted chiefly of galena, pyrite, sphalerite, and chalcopyrite in a gangue of

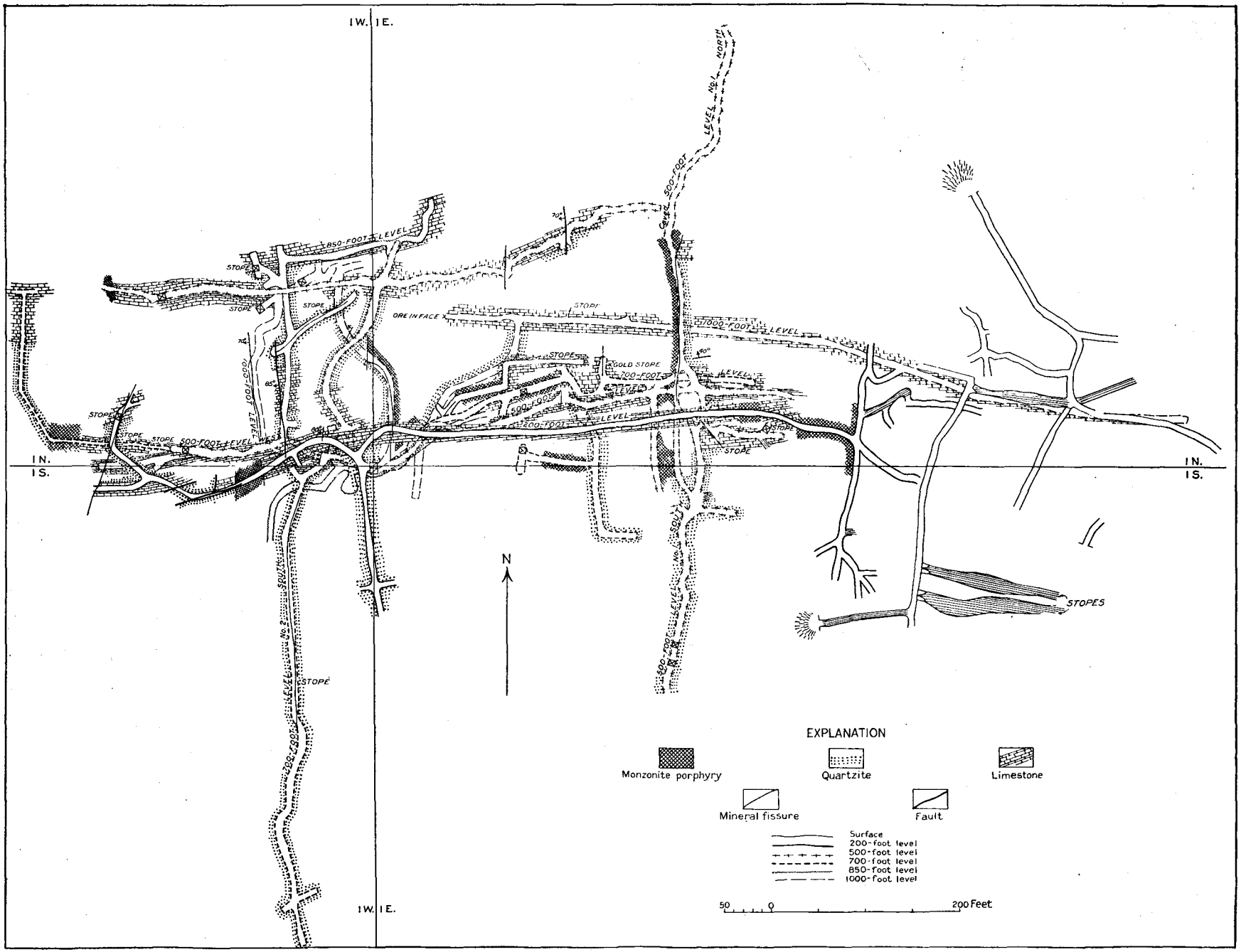


FIGURE 21.—Map of the Ben Harrison mine, Stockton district

manganiferous calcite and quartz. A little arsenopyrite also occurs. Oxidation has been rather thorough to about 800 feet, although a few residual sulphides are found much higher, and there was some oxidation even at the bottom of the mine. The minerals present in the oxidized ore include plumbojarosite, cerusite, jarosite, malachite, gypsum, and "limonite."

There is no necessity for pumping, as the mine is practically dry even at the 1,000-foot level.

The tenor of the ore mined in recent years averages about 22 per cent of lead and 13 ounces of silver and $1.30 in gold to the ton, with a little copper. A rich shoot of gold ore above the 700-foot level in the footwall of the east porphyry dike averaged $17 in gold to the ton, but this is decidedly exceptional.

The mine formerly operated a concentrating mill, but this had been dismantled for some years at the time of this survey, in 1927. The low-grade ores were sorted by hand to bring them to shipping grade.

CALUMET

The Calumet mine is in the NE. ¼ sec. 30, T. 4 S., R. 4 W., in the foothills of the Oquirrh Mountains. It is reached by wagon road from Stockton, which is about 1½ miles due west. The mine was operated in the early days and is reported to have been a rather large producer, but no exact information as to its output is available. During the World War it was reopened after long idleness, and somewhat more than $60,000 was produced to 1920. Since that time it has been idle. The mine is reported to be opened by a shaft 600 feet deep, but the workings are full of water and inaccessible.

The mine is in the Oquirrh formation, about 4,000 feet above the base. The ore is reported to have occurred on the intersection of a fissure that trends N. 20° W. and dips 85° E. with a limestone bed that strikes N. 70° W. and dips 70° N. Specimens on the dump indicate that the ore was highly pyritic and quartzose. Galena, sphalerite, and chalcopyrite were observed as primary sulphides, and sulphur, malachite, and "copper pitch" as oxidation products.

The average tenor of the ore mined during the World War was 18 per cent of lead, 0.25 per cent of copper, and 12 ounces of silver and $2.50 in gold to the ton. This gold average is considerably higher than that of any other mine in the district.

GALENA KING

Location, production, and development.—The Galena King mine is in the foothills of the Oquirrh Mountains, about 1½ miles northeast of Stockton, from which it is reached by a wagon road. The property, which has long been one of the most valuable in the Rush Valley district, consists of the Galena King, Silver King, Silver King No. 2, Silver King West Extension, First Extension West of Silver King No. 2, Theresa, and other claims. The claims were mostly located in 1865, and the first galena ore shipped from Utah was produced from this mine. The mine was only sporadically operated in the period between 1880 and 1900 but had been active from about 1908 to the time of this survey, in 1927, when it was under lease to F. A. Dederich and associates.

The mine has been a steady producer, although not a very large one. Probably the total output somewhat exceeds $1,000,000, although this is an estimate only, as nothing is precisely known of its production in the early days.

The mine is developed (see pls. 30 and 32) by means of two inclined shafts, one 500 feet deep, the other 1,000 feet deep. Levels have been driven at 300, 400, 500, 600, 650, 800, 900, and 1,000 feet, and two long crosscuts on the 300-foot level. Fully 8,000 feet of development work has been done in the mine.

Geology.—The productive workings of the Galena King mine have been practically confined to a 20 to 40 foot limestone bed in the Oquirrh formation. This bed, locally known as the "Galena King" limestone, is 1,100 feet stratigraphically higher than the "Honerine" limestone. It has been the productive bed in the Argent, No You Don't, and Tiptop mines, and probably in the Bullion mine also.

The beds of the Oquirrh formation strike almost due east and dip about 65° N. in the Galena King mine, in conformity with the general structure on the northeast limb of the Ophir anticline. The strata are cut by a number of northward-trending, chiefly westward-dipping fissures with a few faults. Two monzonite porphyry dikes occur in the mine, striking and dipping conformably with these fissures. The "Galena King" limestone is notable for the presence of the "Galena King gouge" which almost invariably accompanies it. This gouge is "limonitic" sericitic material with some jarosite, ranging in thickness from an inch or so up to over a foot. In places it is near or at the footwall of the limestone, but elsewhere it occurs at a higher horizon, though rarely above the middle. This gouge is considered by the operators an index feature of the ore bodies, and in exploration by drifts it is followed as the most favorable part of the limestone. The gouge is probably due chiefly to shearing within the limestone when the strong folding of the beds occurred but owes its present mineralogy to oxidation of the probably hydrothermally altered gouge material.

Only a few small faults occur in the mine. Probably the largest is the one known as the 45° fault, from the fact that that is its approximate dip. This fault

is cut by the east drift on the 300-foot level about 400 feet east of the shaft, where the displacement is rather small, almost surely not over 20 feet. On the 500-foot level the fault is penetrated about 180 feet east of the shaft and on the 800-foot level about 50 feet east. Here it shifts the west side northward about 70 feet referred to the east side and is marked by a thick breccia zone. Presumably the shaft passes through this fault between the 800 and 1,000 foot levels, but this part of the mine was inaccessible at the time of this survey.

Another fault is seen on the 800-foot level about 200 feet west of the shaft. It strikes about N. 20° W. instead of due north, like most of the others, and shifts the west side north about 40 feet. The fault is not recognizable at higher levels, however. A small scissors fault occurs at the west end of the 300 stope on the 300-foot level of the mine. This has a steep east dip of about 70° and on the 300-foot level offsets the west block north about 35 feet, but on the surface the displacement is about 30 feet in the opposite sense.

The ore bodies of the mine occur as blanket and chimney deposits, replacing the "Galena King" limestone along the gouge zone. The large stope west of the shaft which extended from the 300-foot level almost to the surface showed no control of the ore body by north-south fissures. The ore formed a blanket deposit about 300 feet long and wide and from 1 to 6 feet thick. A chimney deposit about 35 feet wide connected with this stope and continued to the 800-foot level and, somewhat less strongly, even to the 1,000-foot level. A number of stopes east of the shaft occur along the intersection of the north-south faults and fissures and the "Galena King" limestone.

The ore of the mine was largely oxidized to a depth just above the 800-foot level, although galena was found in quantities almost to the surface. Between the 800 and 1,000 foot levels the ore was made up chiefly of galena with a little sphalerite, chalcopyrite, and pyrite; above this level it was chiefly cerusite, jarosite, malachite, plumbojarosite, and "limonite." Little evidence of alteration is seen in the limestone except the presence of the sulphide minerals, although locally there is a small development of hornfels.

The ore mined in the early days consisted of both oxidized and sulphide ore. The sulphide ore is reported to have averaged 50 per cent of lead and 40 ounces of silver to the ton. In recent years the ore has shown an average tenor of about 30 per cent of lead, 8 ounces of silver to the ton, and a little copper and gold. Some zinc ore was also shipped, but its tenor is unknown.

HONERINE

Location, development, and production.—The Honerine mine is by far the largest in the Rush Valley district. It is in the foothills of the Oquirrh Mountains about a mile northeast of Stockton. It is operated through a long adit tunnel from Bauer, about 1½ miles north of Stockton, at the south end of Tooele Valley.

The Honerine is one of the oldest claims in the district and was located by General Connor in 1865. Consolidation of the claims into larger units has gone on for a long time, and in 1910 the Bullion Coalition, consisting of 77 patented claims and fractions, was formed. In 1924 this property was taken over on option by the Combined Metals Reduction Co., which had for some time maintained a selective flotation plant at Bauer. Through all these changes and consolidations the mine is still known locally as the Honerine.

The property was first worked by means of inclines, following down the intersection of the productive limestones and the fissures. After this period, when each claim had its own shaft, a drain tunnel was driven about 600 feet lower than the mouth of the Honerine incline, and several ore bodies were mined through it. This adit, now called the 600 level, was driven from the bottom of the gulch in sec. 19, T. 4 S., R. 4 W., and is reached by the wagon road that also serves the Galena King mine. After the Bullion Coalition was formed the present drain tunnel and haulage level, called the 1,200 level, was driven from Bauer. This tunnel is over 13,000 feet long and effectively drains the country to a depth of about 1,200 feet below the portal of the old Honerine incline. Winzes were sunk to a depth of 400 feet below this level, and the lower levels are now being worked through them at considerable expense for pumping. The tunnel discharges about 1,500 to 1,900 gallons of water a minute, which suffices for the needs of the mill and in addition is used to irrigate 160 acres of orchard and 200 acres of alfalfa land. All together the development workings in the property aggregate over 50,000 feet, exclusive of stopes.

The production in the mine has been large. In the early days the mine was vigorously worked, and the production to 1890 has been estimated at $1,250,000, from 80,000 tons of ore. Between 1890 and 1901 there appears to have been very little production, but activity was renewed soon afterward. The production of the mine from 1901 to 1927 may be estimated at about $6,000,000. From 1912 to 1927 the mine was operated in part by lessees and in part by the owners.

Geology.—The workings of the Honerine mine (see pl. 31) are all in the Oquirrh formation, which consists of a great series of interbedded quartzites and limestones. The mine is about 5,000 feet above the base of the formation.

The stratigraphy of this part of the Oquirrh formation has been carefully investigated in the mine, and the following section, kindly furnished by W. A.

Young, geologist of the company, with some slight changes based on work of the writer, represents the sequence there determined.

Section of part of the Oquirrh formation in the Honerine mine

[With names of the productive limestone beds in local use by the miners]

	Feet
Quartzite.	
"Galena King" limestone	20
Siliceous limestone and sandstone	20
"Little" limestone	3
Quartzite	20
Limestone	10
Quartzite	160
"Rambler formation" (siliceous thin-bedded limestone)	180
"Rambler" limestone (rather pure limestone)	4
Quartzite	90
"Hercules" limestone	2
Quartzite	150
"St. Patrick" limestone	14
Quartzite	140
"North Ada" limestone	3
Quartzite	18
"South Ada" limestone	8
Quartzite and hornfels (the lower 100 feet chiefly hornfels)	230
"Maverick" limestone (only locally present)	5
Quartzite and hornfels	40
"Honerine" limestone	8
Quartzite and hornfels	10
"Little Honerine" limestone	1
Quartzite and hornfels.	

The thicknesses given in this section are only approximate, and there is considerable variability in the beds. For instance, the "Honerine" limestone is locally as much as 12 feet thick; the "Galena King," 45 feet. Considerable strike faulting has occurred along many of these limestone beds, seemingly because during the folding they offered less resistance to shear than the quartzite. This may be the cause of some of the variations in apparent thickness of the beds. For example, the "Hercules" limestone ranges in thickness from 4 feet down to a knife-edge and for some distance on the drain-tunnel level is represented merely by a shear zone with sporadic horses of limestone.

The attitude of the beds in the Honerine mine is very regular. They strike almost uniformly N. 70°–75° W. and dip about 60°–75° NE. They are, however, sliced by a multitude of faults and fissures, locally called "crossings." These faults and fissures strike between N. 40° W. and N. 40° E., but by far the greater number are more rigorously confined to trends of N. 10°–30° E. Nearly all dip westward at angles between 45° and the vertical, mostly between 60° and 75°. Many of these fissures show little or no displacement of the rocks, but others have offset the beds several scores of feet. The intersections of the faults and fissures with the limestone beds have been the sites of the chief ore bodies of the district, and the more productive of them have received names. In order from east to west, the productive crossings are called the Chico, Weir, Katherine, Basin, Kimberley, Shewee, Buhl, Palace, Glory Hole, and Legal Tender. The Knickerbocker fault west of the Legal Tender crossing is apparently unmineralized.

The displacement on these fractures is commonly rotational. The Knickerbocker fault displaces the west block 10 or 15 feet to the north on the 1,200-foot level, but on the 600-foot level the displacement is about 120 feet, the west block having moved relatively south. Similarly, the Palace crossing shows a displacement of 60 feet on the 600-foot level, the west block having moved relatively south, but on the 1,200-foot level the displacement is negligible.

The fault which according to the interpretation independently reached by Mr. W. A. Young and the writer is much the largest in the district is that which on the surface passes just east of the Black Diamond shaft. This appears to have a horizontal displacement of about 800 feet, the west side having moved relatively south. A thin-bedded cherty limestone of which about 60 feet is exposed crops out at the Black Diamond shaft. This limestone is very similar lithologically to the "Paisley" limestone, whose normal position is about 550 feet above the "Galena King" limestone. A similar limestone is intersected by the drain tunnel about 250 feet northwest of the Bullion crosscut, at about the position to be expected from the observed attitude of the beds. If the identification of this bed as the "Paisley" is correct, then the Bullion workings are in the "Galena King" limestone, for the stratigraphic interval between them is about equal to the interval measured on the surface between these beds. The fault can be traced north on the surface, passing a short distance west of the Southport mine and about 300 feet west of the Muerbrook mine. At the Muerbrook locality there is a strong drag, the "Larsen" limestone having been bent at least 75 feet out of strike toward the south, in the sense required by a strong movement of the west block southward along the fault. Other beds than the "Paisley" and "Galena King" limestones have not been identified west of this fault, the exposures being very poor, so the interpretation just made must be considered unproved though very probable.

Besides these fractures, several monzonite porphyry dikes penetrate the strata. These bodies range in thickness from a foot or two to over 300 feet, the thickness of the body locally known as the "Raddatz porphyry." Like the fractures, the dikes generally trend north and dip west, though they are rather irregular in outline. They are commonly associated with and subparallel to the faults and fissures, which are therefore thought to have controlled them at least in part.

The ore bodies of the Honerine mine are characteristically pipelike or tabular replacement bodies in limestone, following the intersections of the fissures with the limestone beds. As a rule the ore bodies are the full width of the limestone at the fissure, tapering in cross section away from it. The bodies are locally 100 feet in strike length but more commonly the dimensions are only 10 feet or so. In pitch length some of the ore bodies, notably the Palace shoot and Basin shoot on the "Honerine" limestone, have been followed for over 1,800 feet, from the surface to the 1,600-foot level, where they still persist. Many of the shoots are not persistent, however, for more than a few scores of feet.

Ore has not been formed at every intersection of a fissure with the limestones, certain beds being much more favorable than others. The "Honerine" limestone is the most favorable bed, or at least the largest ore bodies yet developed have been found in it. The "St. Patrick" limestone is also a very productive bed. The "North Ada," "South Ada," "Hercules," and "Rambler" limestones are less mineralized. The crossings differ similarly. The Weir, Katherine, Basin, Buhl, and Palace are the most consistently productive fissures, the Basin and Palace being perhaps the best.

Some of the ore bodies, of which that in the Hampden stope in the "St. Patrick" limestone is typical, do not appear to be particularly associated with any north-south crossings. In the Hampden stope, although it is close to the projected position of the Palace crossing and may be connected with it, there is a closer association with a gently arcuate fault, which is subparallel to the bedding. In the opinion of Mr. Hampden, who was in charge of the development here, the association with the east-west fault was the controlling feature of the ore shoot. Similar widening of shoots in places where east-west faulting has been strong is observable in the Palace ore shoot in the "Honerine" limestone, both in the drain-tunnel level and on the 1,600-foot level.

There have been at least five periods of faulting in the Honerine mine. Early east-west faulting occurred along many of the limestones. Both hanging wall and footwall of the "Honerine" limestone are formed by strike faults on the 1,600-foot level for some distance, and the "St. Patrick" and Hercules" limestones also show the same thing. This east-west faulting was followed by the north-south faulting that produced the crossings and then by the porphyry intrusions. The porphyry was later faulted by both east-west and north-south faults of slight displacement (a few feet as maxima). Mineralization then occurred along fissures of all these periods, and locally, as in the Connor stope just above the 1,600-foot level, there has been some postmineral east-west faulting.

The hypogene ore of the mine consists of mixed sulphides, pyrite, galena, sphalerite, and a little chalcopyrite and arsenopyrite being most abundant. Tetrahedrite has also been reported but was not determined in this survey. The relative abundance of the different sulphides varies greatly from place to place in a given shoot. In some places galena is concentrated, elsewhere sphalerite, and elsewhere pyrite, without apparent system. Gold also occurs locally in quantities as great as $19 a ton, although this is decidedly unusual.

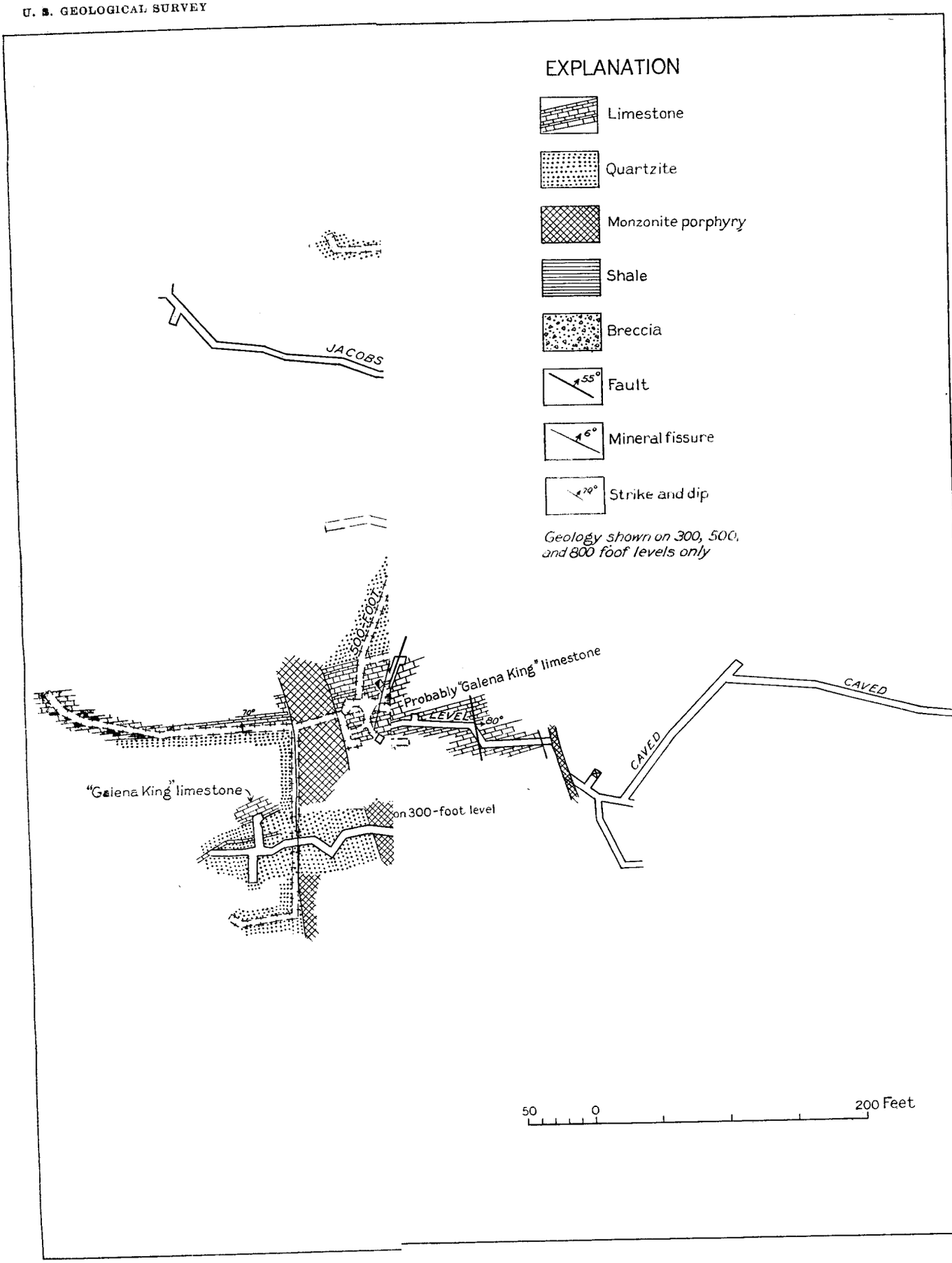
Few gangue minerals have been developed in the productive limestones alongside the sulphides. Quartz is almost the only one that is at all abundant, although wollastonite, diopside, epidote, fluorite, dolomite, and chlorite have been developed in the limy sandstones and in the porphyries near the ore bodies.

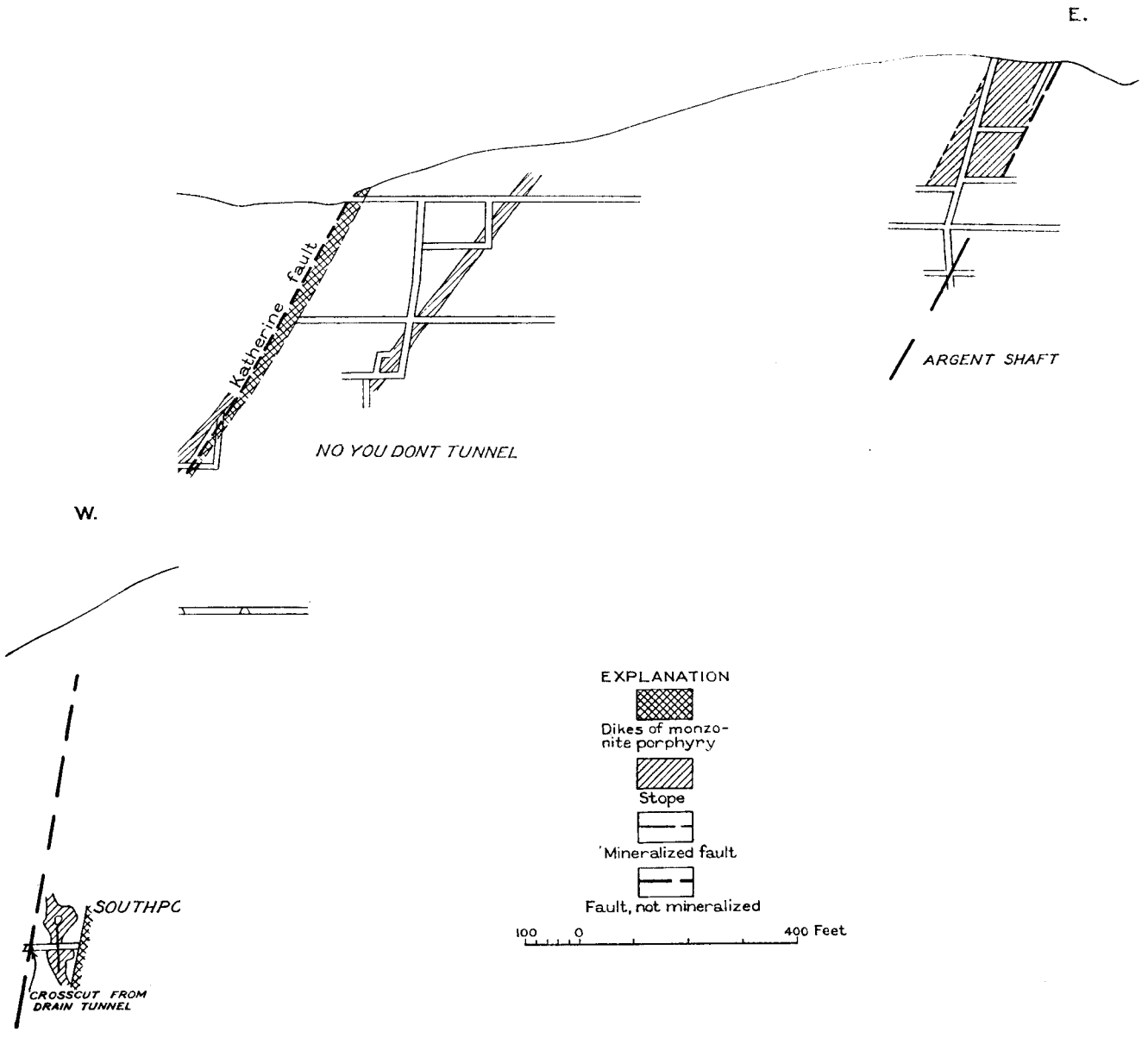
Oxidation has altered the hypogene sulphides to a mixed ore, composed of cerusite, plumbojarosite, jarosite, malachite, smithsonite, aurichalcite, pyromorphite, and "limonite." Small amounts of anglesite, mimetite, beudantite, and wad also occur. The depth of oxidation is variable through the mine. A certain amount of oxidation has occurred to the greatest depths yet attained, but as a rule a transition zone between oxidized and sulphide ore occurs about 400 feet above the drain-tunnel level. This zone rises somewhat to the east and varies somewhat from one limestone to another. The "Galena King" limestone was apparently more permeable to the ground water than the other limestones, and accordingly ore bodies in it are more deeply oxidized.

The tenor of the ore is variable. The average lead shipping ore runs about 18 per cent of lead (maximum 33 per cent), with 6½ ounces of silver to the ton (maximum 12 ounces), 3 per cent of zinc (maximum 6 per cent), 18 per cent of iron (maximum 25 per cent), 0.25 per cent of copper (maximum 1.5 per cent), and 70 cents in gold to the ton (maximum $5) on carload lots. The milling ore averages about 8 per cent of lead, 10 per cent of zinc, and 3 ounces of silver, and 50 cents in gold to the ton. The line between shipping and milling ore is dependent primarily upon the zinc content but also upon the amount of oxidation of the ore. The milling ore is handled by selective flotation in a modern well-equipped mill with a daily capacity of about 450 tons.

MUERBROOK

The Muerbrook mine is in the foothills of the Oquirrh Range in the extreme southwest corner of sec. 18, T. 4 S., R. 4 W. It is reached by wagon road from Stockton, a distance of about 1½ miles. The mine was located in the early days but has never been a very large producer. It has been idle since 1922, and many of the workings were caved at the time of


EXPLANATION
Limestone
Quartzite
Monzonite porphyry
Shale
Breccia
55°
Fault
60°
Mineral fissure
70°
Strike and dip
Geology shown on 300, 500, and 800 foot levels only
JACOBS
500-FOOT LEVEL
Probably "Galena King" limestone
70°
80°
CAVED
CAVED
"Galena King" limestone
on 300-foot level
50 0 200 Feet


E.
Katherine fault
NO YOU DONT TUNNEL
ARGENT SHAFT
W.
SOUTHPC
CROSSCUT FROM DRAIN TUNNEL
EXPLANATION
Dikes of monzonite porphyry
Stope
Mineralized fault
Fault, not mineralized
100 0 400 Feet

this survey, in 1927. Its total production is unknown but perhaps about $200,000, of which about half was produced within the 10 years preceding 1922. The mine is developed by means of an incline about 420 feet deep at an angle of 44°. From this incline four short levels are turned 100, 130, 170, and 290 feet below the collar. Probably the total workings of the mine do not exceed 2,000 feet.

The mine is in the Oquirrh formation about 2,500 feet stratigraphically higher than the "Galena King" limestone, hence about 7,500 feet above the base of the formation. Many of the workings are in a limestone about 15 feet thick called the "Larsen" limestone. This bed strikes almost due east and dips 50°–70° N.

There is an irregular dike of porphyry in the mine, trending almost east-west. It is considerably sliced by faults, along with the inclosing sediments, so that its normal attitude is uncertain, but its general dip is steeply north. The country rock in the vicinity of this dike is much shattered, and the principal breccia zones trend east and about N. 30° E.

The ore bodies of the mine were apparently tabular replacement deposits in the shattered footwall of the dike, raking steeply to the east in depth. Both quartzite and limestone were mineralized, but the principal sheets appear to have been in the limestone. Locally the ore made against the footwall of the porphyry, but it was in general a few feet below it. The ore bodies were small, only locally exceeding 3 feet in thickness and 15 feet in width. More commonly the pipes were only 3 or 4 feet in width. Apparently none of the stopes were more than 100 feet in pitch length.

The ore was oxidized to the lowest level of the mine, although a few residual sulphides occurred almost to the surface. The hypogene ore minerals recognized in these residua are pyrite, chalcopyrite, galena, and sphalerite in a gangue of calcite and quartz with a little dolomite. Oxidation products, constituting the ore as mined, include jarosite, plumbojarosite, cerusite, malachite, anglesite, "limonite," and some gypsum and melanterite.

The average tenor of the ore was about 38 per cent of lead, 0.5 per cent of copper, and 13 ounces of silver and about 70 cents in gold to the ton.

MUSCATINE

The Muscatine mine is in the NE. ¼ sec. 30, T. 4 S., R. 4 W., in the gulch below the Calumet workings. The mine was worked in the early days to a depth of about 300 or 400 feet but had long been abandoned at the time of this survey. Nothing is definitely known of its production, but it was probably slight.

The mine is opened by several inclines, of which the longest is about 350 feet long. It is situated in the Oquirrh formation about 4,000 feet above the base. The beds here strike N. 70° E. and dip 40°–45° N. The ore apparently occurred in a partly marmarized and silicified limestone, in association with several small masses of porphyry. The ore seems to have occurred in northwestward-pitching shoots, in some stopes above 30 feet wide, in others only 10 feet wide. These shoots were commonly connected along the strike by thin leads of mineralization. Jasperoid and hornfels occur abundantly in the mine, and both these varieties of rock are mineralized as well as the marble. The limestone is much fractured and carries stringers of sulphides; so also do the hornfels and jasperoid. About 350 feet down the dip the stopes cut off against a northwestward-trending fault, and no prospecting appears to have been done farther northeast.

The mine is somewhat different from the larger number of mines in the district in the more conspicuous development of hornfels with the ore. Pyrite, sphalerite, and galena seem to be the dominant hypogene sulphides, and jarosite, cerusite, plumbojarosite, and "limonite" are the common oxidation products.

SALVATION-HERCULES

The Salvation-Hercules mine is in the northeastern part of the Rush Valley district, in the gulch above the Ben Harrison mine, at an altitude of about 6,300 feet. It is reached by wagon road from Stockton, about 3 miles away. The mine was located in the early days of mining in the district, and little is known of the production. It was probably small, however, as the workings are not extensive and the visible stopes are not large. At the time of this survey the mine was being operated in a small way by lessees.

The mine is developed (see fig. 22) by means of an adit about 1,200 feet long, from which a few winzes and raises are turned. The mine is in the Oquirrh formation, about 8,000 feet above the base. The beds stand vertical or are overturned a few degrees to the south. The strike is essentially east. The beds are cut by a northeastward-trending porphyry dike along which the first 50 feet of the adit is driven. The adit then turns west into the hanging wall of the dike and follows a strong fissure and breccia zone, locally called the Katherine fissure, for practically all its length. Toward the face of the tunnel about 1 foot of sheared porphyry occurs in the fissure. This fissure and breccia zone trends about N. 10° E. and dips about 70° W. A few short winzes and raises follow this zone below and above the adit level. About 500 feet from the portal the crosscut intersects a limestone bed along which a prospecting drift has been run a short distance.

The ore bodies of the mine occurred as breccia fillings and replacement deposits in the quartzite walls of the Katherine fissure. The stopes were small—

about 4 or 5 feet wide, a few tens of feet high, and about 200 feet long. The ore was chiefly oxidized and as mined consisted of cerusite, plumbojarosite, cerargyrite, malachite, jarosite, and limonite, with residual fragments of the hypogene pyrite, galena, and chalcopyrite that were originally deposited.

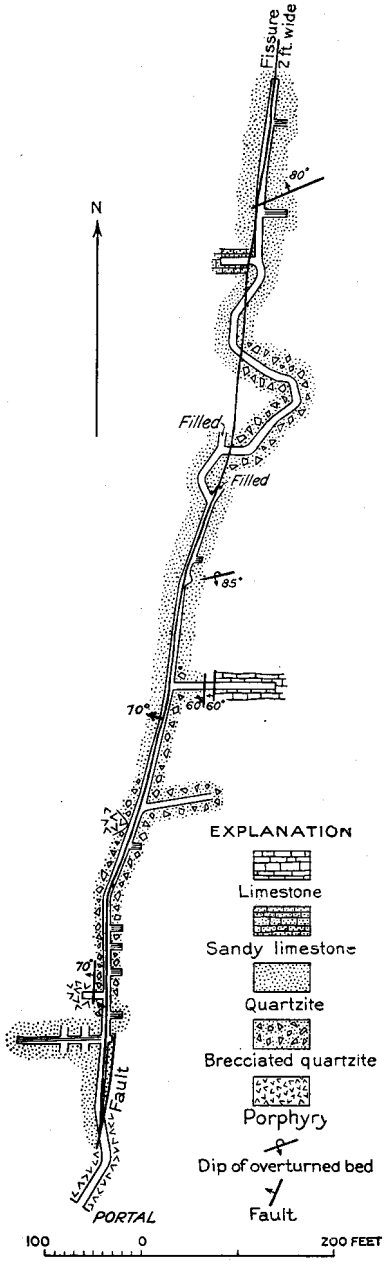


FIGURE 22.—Map of the Salvation-Hercules mine, Stockton district

The tenor of the ore mined in recent years is about 16 per cent of lead, 20 ounces of silver and 30 cents in gold to the ton, and a little copper.

SOUTHPORT

The Southport mine is in the NW. ¼ sec. 19, T. 4 S., R. 4 W., about a quarter of a mile north of the portal of the 600-foot level of the Honerine mine. It is reached by wagon road from Stockton and has been connected on the drain-tunnel level with the main Honerine workings. The mine was developed in the early days of the district and made a small production at that time. Since then it had been worked in only a sporadic manner until the World War. It was then active until 1920, but since then no production had been reported to the end of 1927. At the time of this survey the property was dismantled. Its total production was probably less than $30,000.

The shaft collar of the mine is on the outcrop of the "Paisley" limestone, and presumably the workings are chiefly in this member, but as they were inaccessible at the time of this survey no definite statement can be made.

The ore mined during the most recent activity of the mine averaged about 15.5 per cent of lead, 0.7 per cent of copper, and 5 ounces of silver and 40 cents in gold to the ton.

TIPTOP

The Tiptop mine is just northeast of the Honerine air shaft, near the middle of sec. 19, T. 4 S., R. 4 W. The Cyclone and Tiptop claims are included in the property. It is reached by a wagon road from Stockton, a distance of about 1½ miles, but was being worked at the time of this survey through the drain tunnel of the Honerine mine, with which it is connected by a crosscut about 400 feet long. The mine was not actively worked until recent years, although it had been prospected in a small way for some time. At the time of this survey it was being energetically developed under the ownership of the Stockton Lead Co. The period of notable production of the mine dates only from 1924. Probably somewhat over $300,000 had been produced to the end of 1927.

The mine is developed by a few short drifts and a winze about 900 feet deep, which extends to a depth about 120 feet below the drain-tunnel level of the Honerine mine. Probably the total development workings of the mine do not exceed 2,000 feet, exclusive of the stopes. (See pl. 32.)

The mine is almost entirely in the "Galena King" limestone in the Oquirrh formation, which at the surface dips about 60° N. and strikes about east. In depth, however, a prominent "bedding roll" occurs, so that on the drain-tunnel level the beds strike almost due north. The principal ore shoot of the mine occurs on this bedding roll, in association with a fissure. The ore body at the drain-tunnel level is over 100 feet long and 8 or 10 feet high. The shoot continues at least to the 700-foot level and possibly to the surface, as does the one about 250 feet east which was followed by the winze from the surface. At the time of this survey active work was being carried on in a drift 120 feet below the drain-tunnel level on the "Galena King" limestone west of the winze.

The ore of the Tiptop mine is like that of the stratigraphically lower beds mined in the Honerine and consists of galena, sphalerite, pyrite, and chalcopyrite as primary minerals. Oxidation has occurred about to the 700-foot level.

The average tenor of the ore mined is about 12 per cent of lead, 0.25 per cent of copper, and 4 ounces of silver and 80 cents in gold to the ton. Owing to the persistence of the ore shoots and the fact that the mine is drained by the Honerine tunnel, so that there are no pumping costs, the property was regarded at the time of this survey as unusually profitable. Neither of the ore shoots had been bottomed at 900 feet below the surface.

SOLDIER CANYON AREA

MARJORIE

The Marjorie prospect, the property of the Soldier Canyon Lead-Silver Mining Co., is in the north side of Soldier Canyon about a quarter of a mile from the mouth. At the time of this survey, in 1927, the developments consisted of a prospecting tunnel about 420 feet long, driven in a N. 10° W. direction from a point about 100 feet above the creek. Throughout its length the tunnel is in the Manning Canyon shale, which strikes N. 70° W. and dips 45° NE. No evidence of mineralization was observed in the tunnel, although, according to John Dorius, secretary of the company, good assays have been reported on samples from the surface.

WEST MOUNTAIN DISTRICT

WEST CANYON AREA

MAYFLOWER

The Mayflower mine is in West Canyon, just above the mouth of Fox Hollow. It is reported to have produced a small amount of ore in the early days of mining in the State, but no record of such production is available.

The old mine was largely caved and full of water at the time of this survey, and the accessible workings consisted only of a few score feet of rather tortuous drifts in the altered limestone of the lower part of the Oquirrh formation. The limestone, which is only a few hundred feet above the base of the Oquirrh formation, has been partly altered to lime hornfels, silicified, and impregnated with pyrite, a little galena, sphalerite, and boulangerite. The sulphides are chiefly distributed along narrow veinlets in the hornfels. The tenor of the ore in sight at the time of this survey was not high, but precise information is not available.

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DRY CANYON FROM HILL WEST OF WANDERING JEW MINE, LOOKING EAST

Prominent ledge cut by road is Jefferson (?) dolomite. Next higher ledge, extending into left foreground, is top of Madison limestone. Above this, poor exposures of the Deseret limestone, Humbug formation, and "Great Blue" limestone extend to the top of the hill. 1, Hidden Treasure mine adit; 2, Granite tunnel of Hidden Treasure mine; 3, Deseret mine; 4, Kearsarge workings; 5, Mono barn; 6, mouth of Hidden Treasure incline; 7, saddle made by Long Trail shale member of the "Great Blue" limestone.

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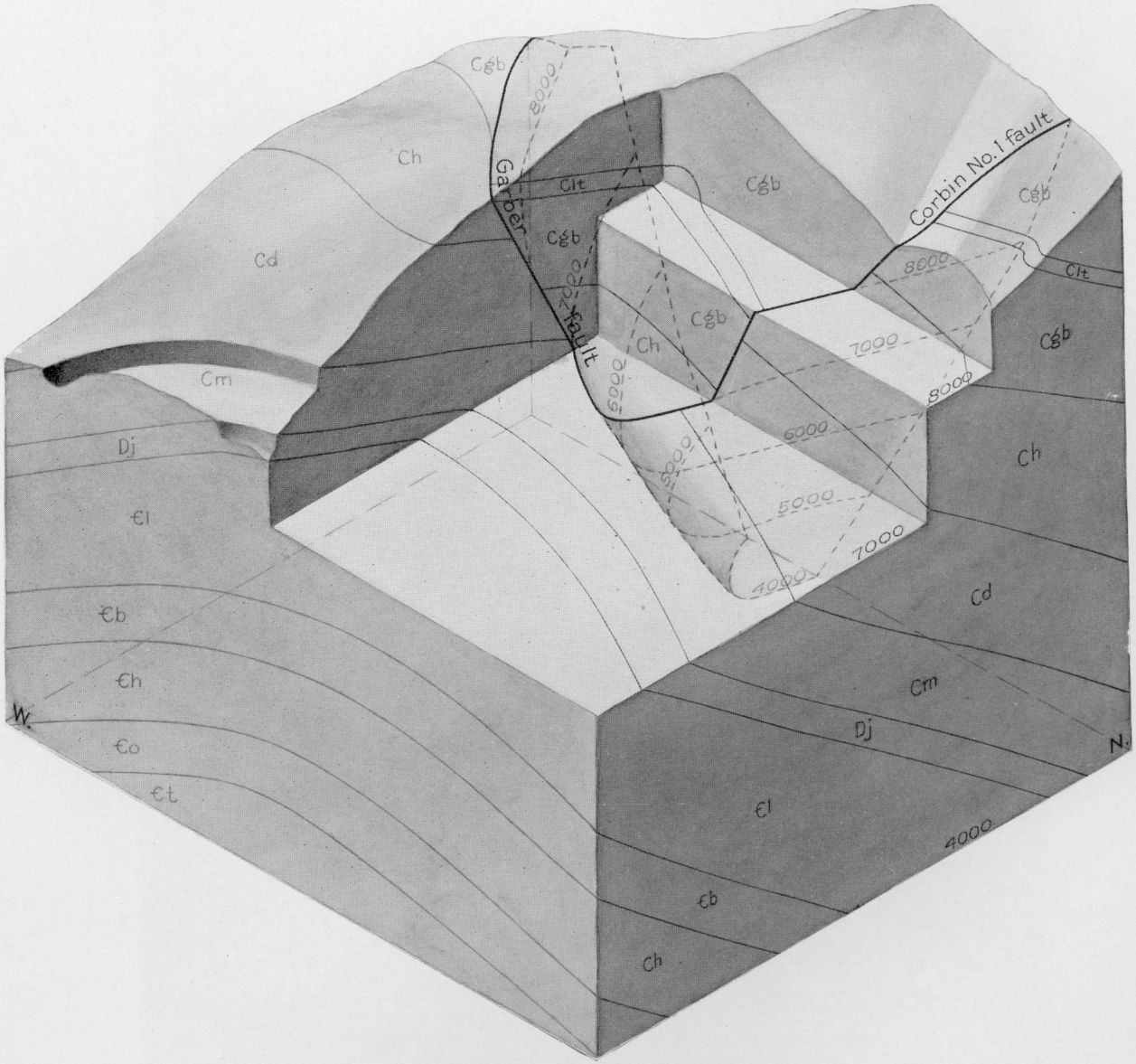


BLOCK DIAGRAM SHOWING RELATIONS OF THE CORBON No. 1 AND GARBER-MARK ANTONY FAULTS TO THE MONO FAULT BLOCK, DRY CANYON

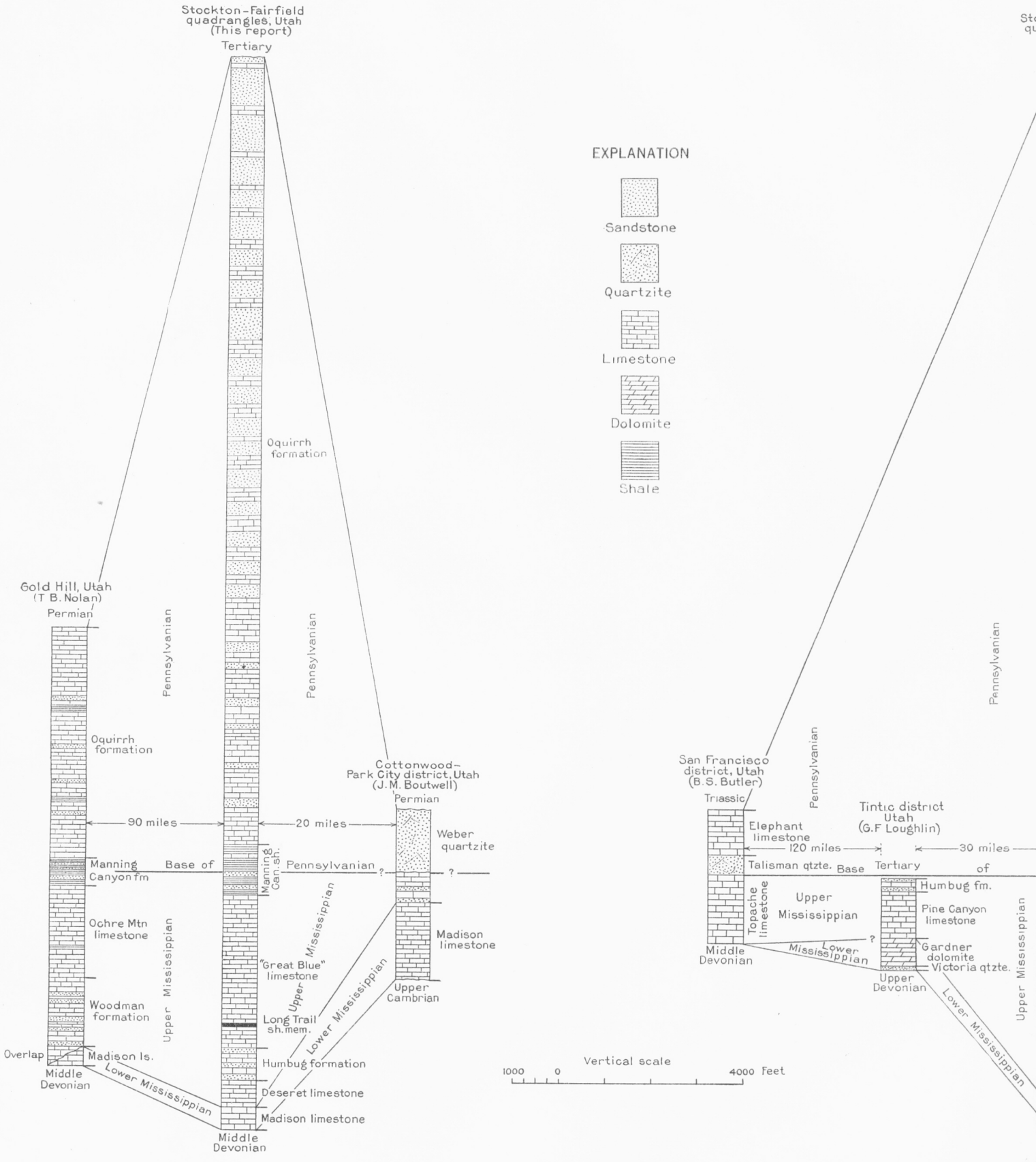
The flat pitch of the keel of the block near the surface is not shown on this diagram.

ROM HILL WEST OF WANDERING JEW MINE, LOOKING EAST

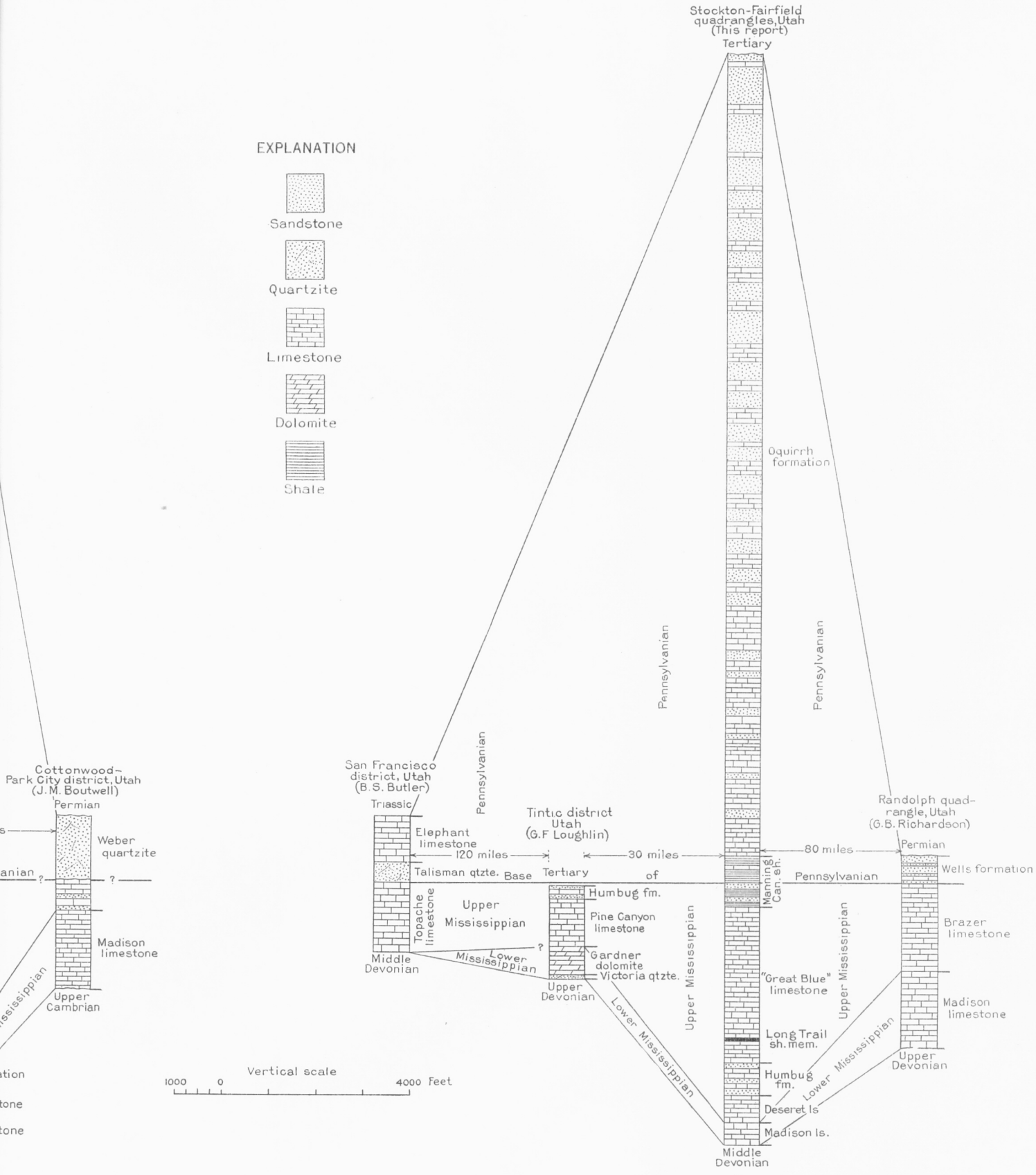
Madison limestone. Above this, poor exposures of the Deseret limestone, Humbug formation, and "Great Blue" limestone extend to the top of the hill. 1, Hidden Treasure mine arge workings; 5, Mono barn; 6, mouth of Hidden Treasure incline; 7, saddle made by Long Trail shale member of the "Great Blue" limestone.

DRY CANYON FROM HILL WEST OF WANDERING JEW MI

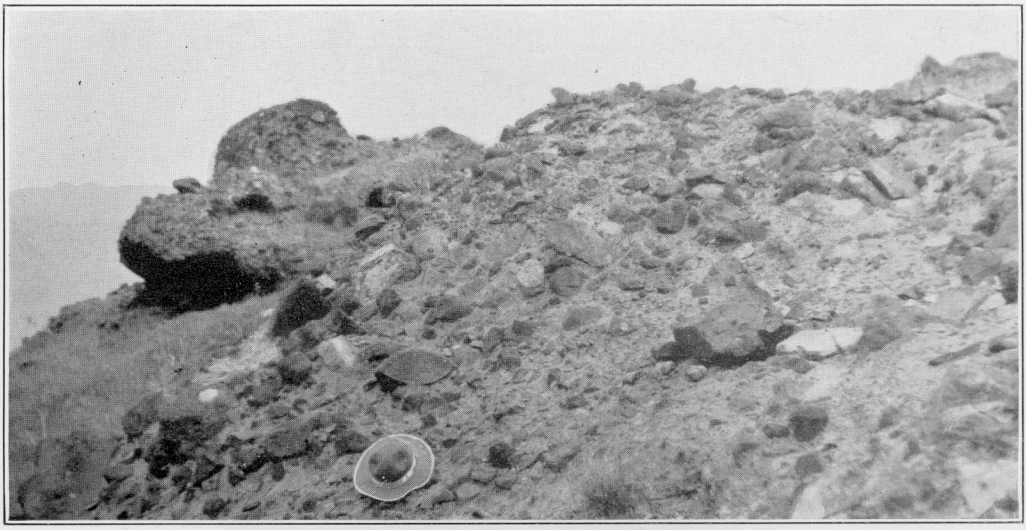
Prominent ledge cut by road is Jefferson (?) dolomite. Next higher ledge, extending into left foreground, is top of Madison limestone. Above this, poor exposures of the Deseret l
adit; 2, Granite tunnel of Hidden Treasure mine; 3, Deseret mine; 4, Kearsarge workings; 5, Mono barn; 6, mouth of Hidden Treasure incli



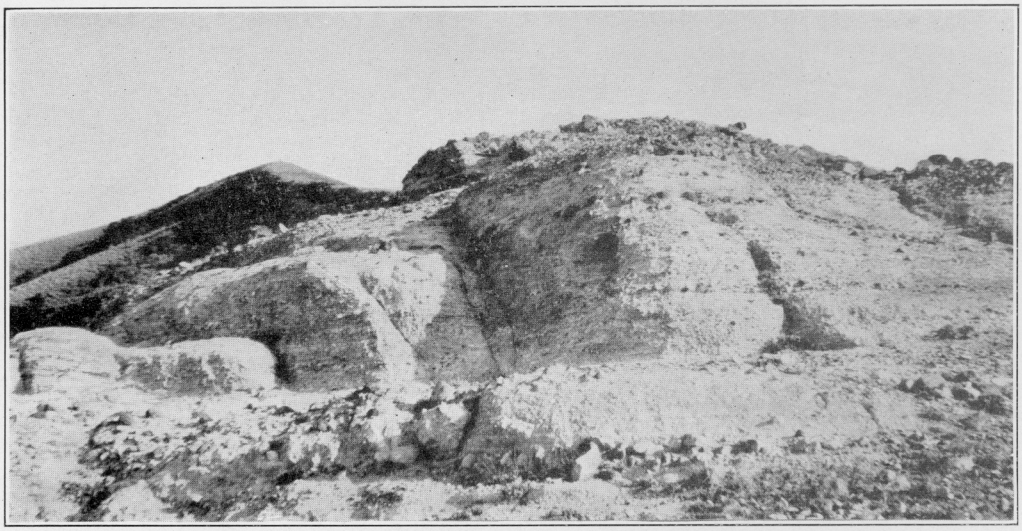
CORRELATION AND VARIATIONS OF MISSISSIPPIAN AND PENNSYLVANIAN FORMATIONS OF WES



AND VARIATIONS OF MISSISSIPPIAN AND PENNSYLVANIAN FORMATIONS OF WESTERN UTAH

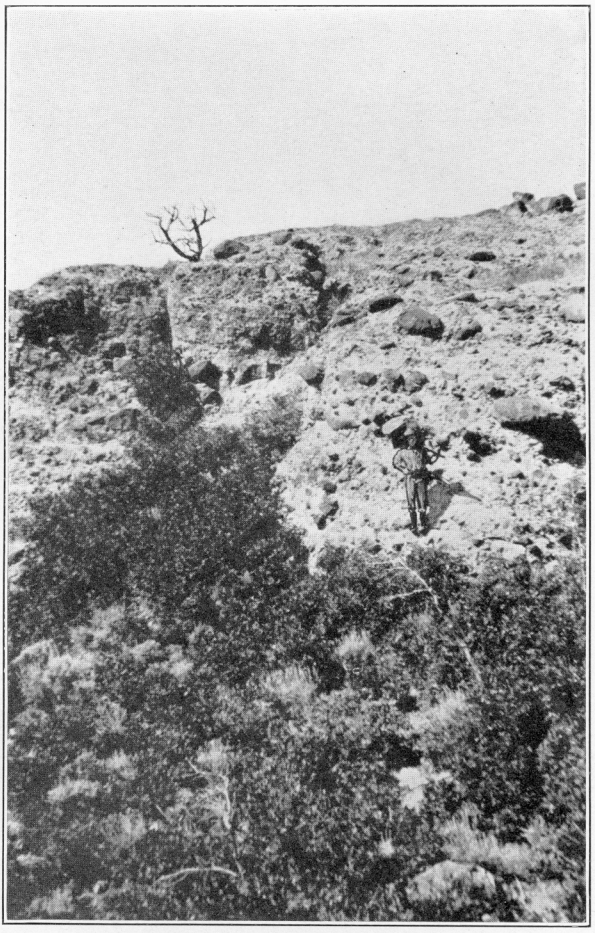


A. ANDESITE BRECCIA AT NORTHEAST FOOT OF SOUTH MOUNTAIN, STOCKTON QUADRANGLE

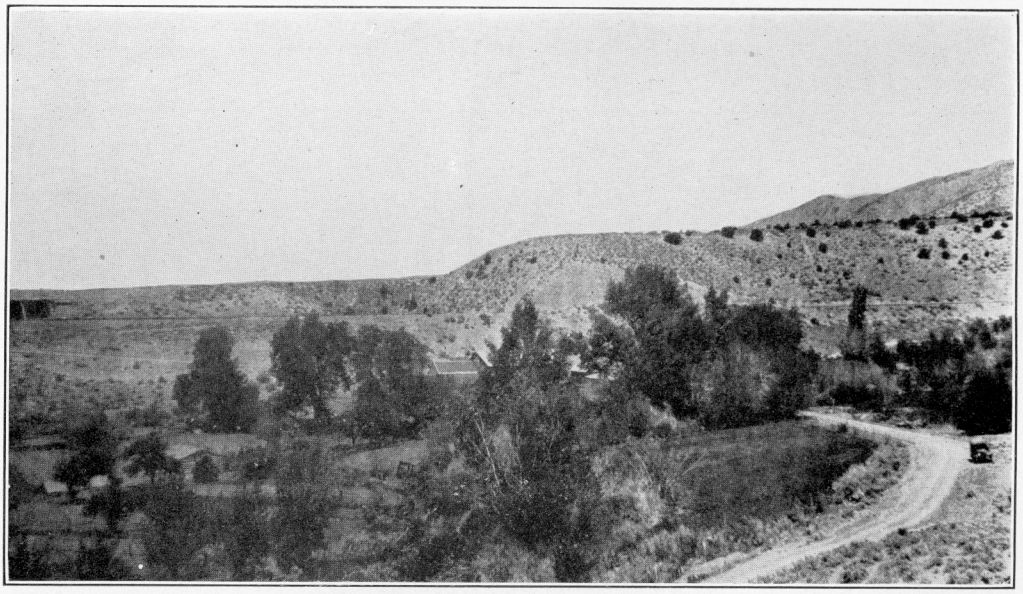


B. VOLCANIC TUFF, OVERLAIN BY ANDESITE BRECCIA, ON DIVIDE BETWEEN STOCKINGS FORK AND CITY CANYON, FAIRFIELD QUADRANGLE

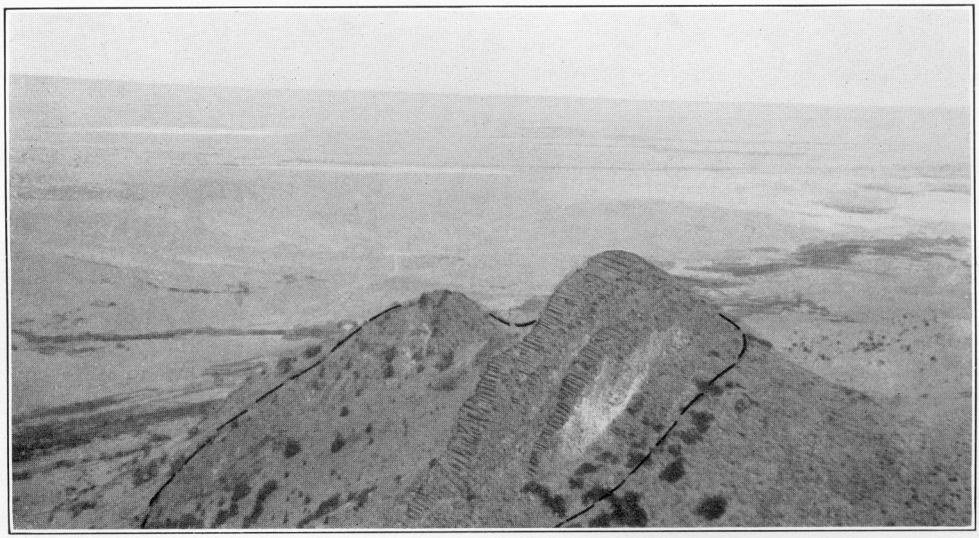
C. WATER-LAID TUFF ON DIVIDE BETWEEN CITY CANYON AND WATER FORK, FAIRFIELD QUADRANGLE



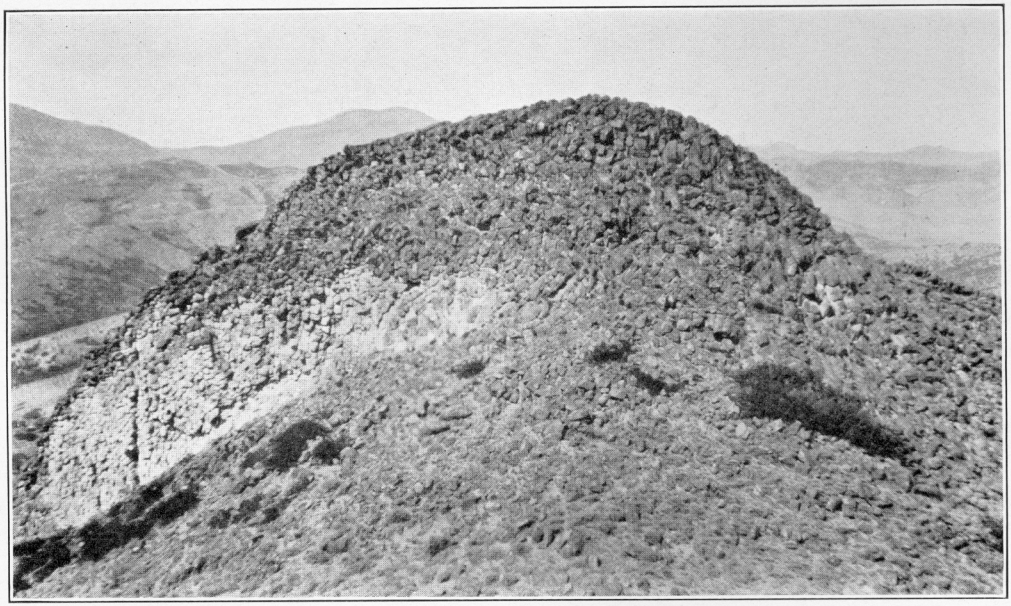
A. LATITE BRECCIA AT HEAD OF OAK SPRING CANYON, FAIRFIELD QUADRANGLE



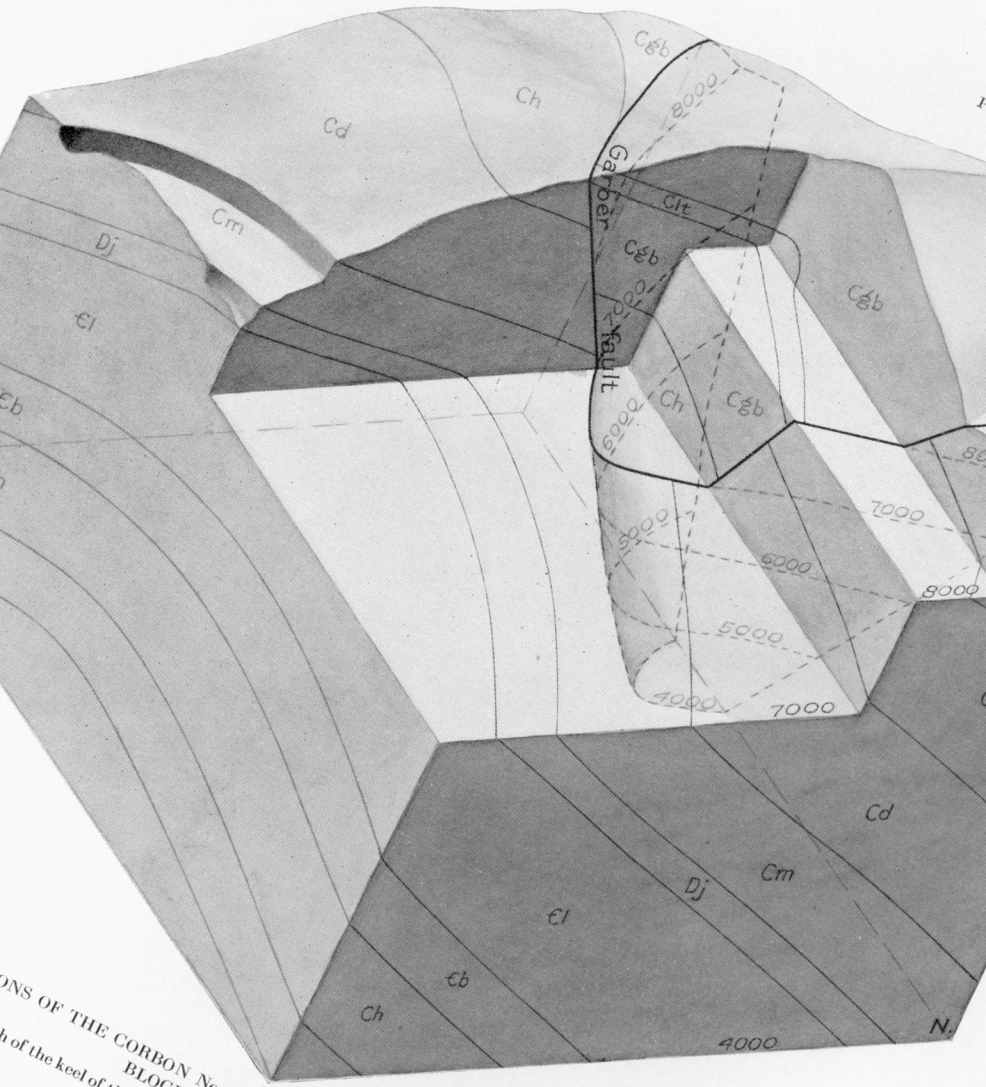
B. SCARP OF WEST MERCUR FAULT IN ALLUVIUM AT BATES RANCH, OPHIR CREEK



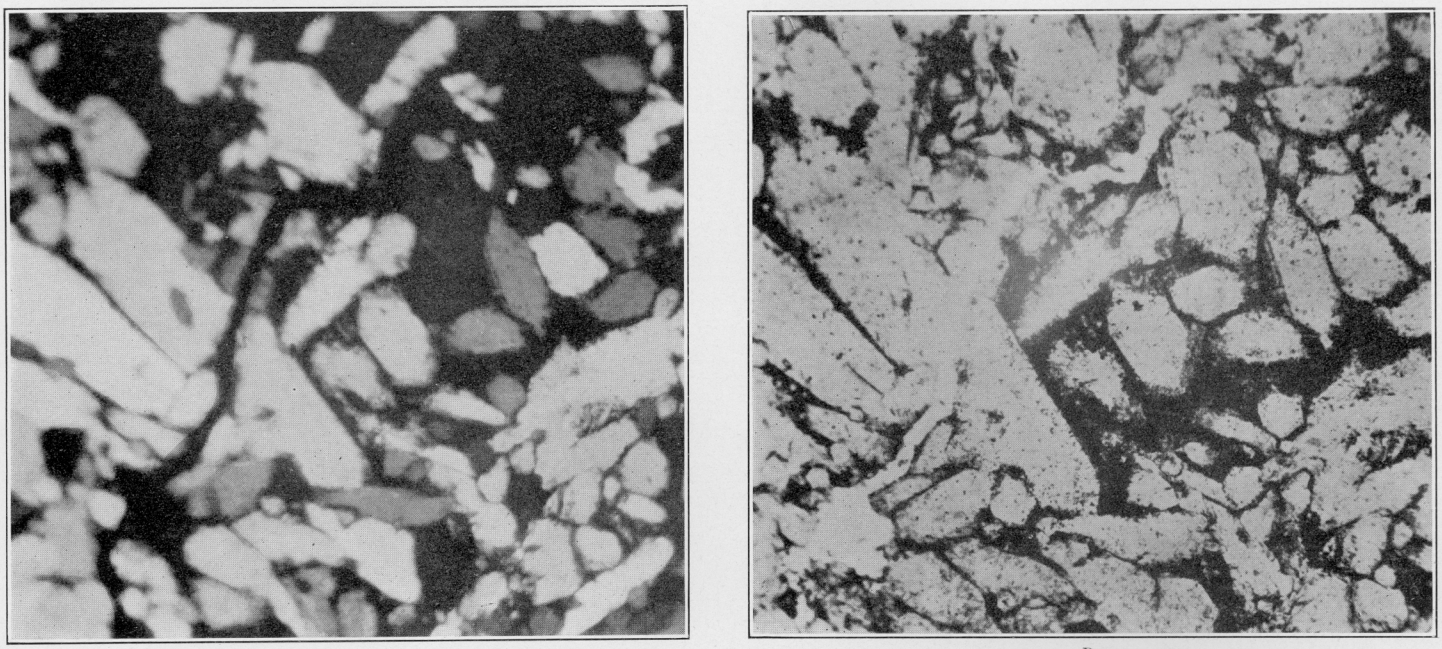
A. STEP MOUNTAIN PLUG FROM SOUTHWEST, SHOWING PART OF THE SUBCIRCULAR RING DIKE



B. STEP MOUNTAIN FROM SOUTHEAST, SHOWING HORIZONTAL COLUMNAR STRUCTURE OF THE RING DIKE SURROUNDING THE CENTRAL PLUG



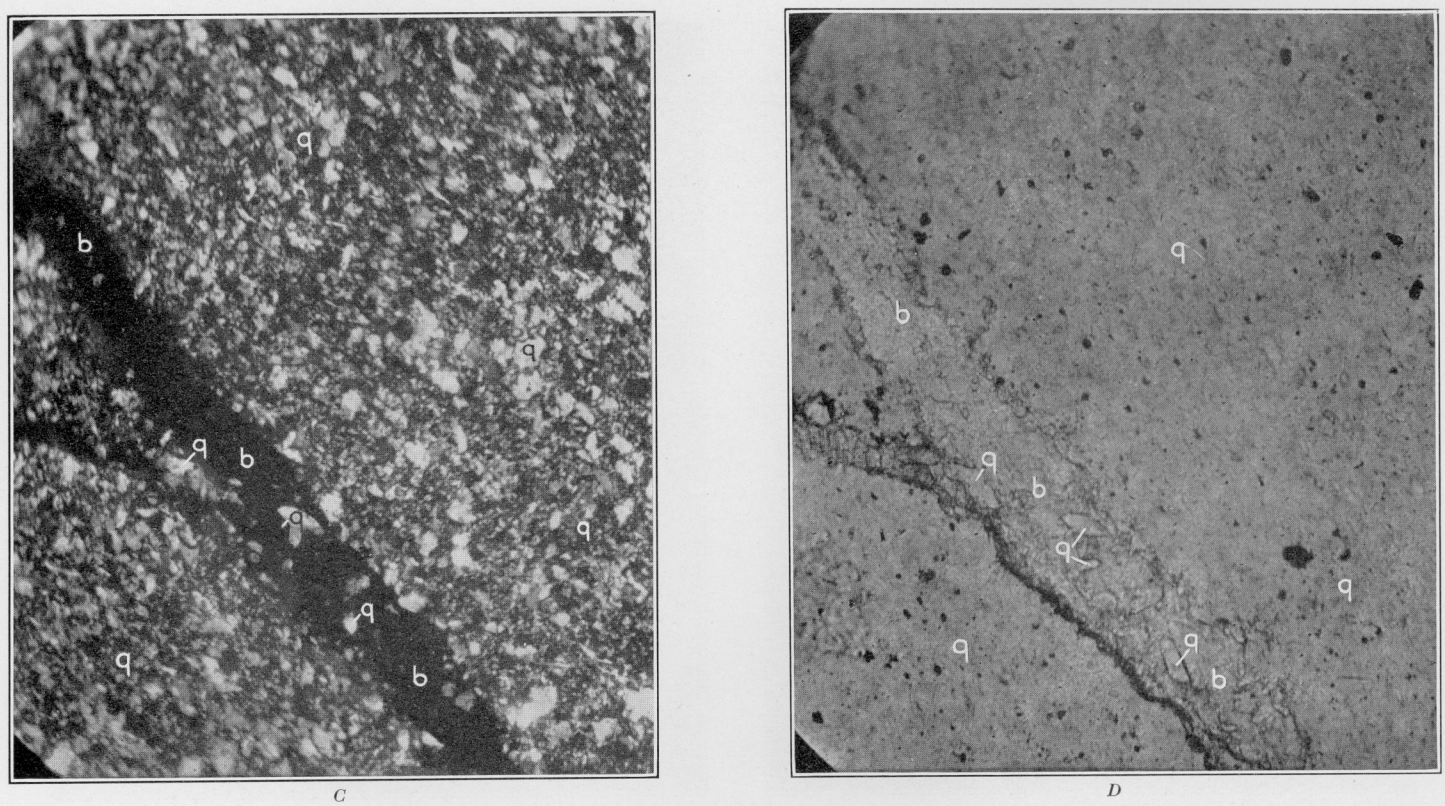
ONS OF THE CORBON No. 1 AND GARBER-A
BLOCK, DRY CANYON
h of the keel of the block near the surf



A B

A, B. "TYPICAL JASPEROID" TEXTURED VARIETY OF JASPEROID

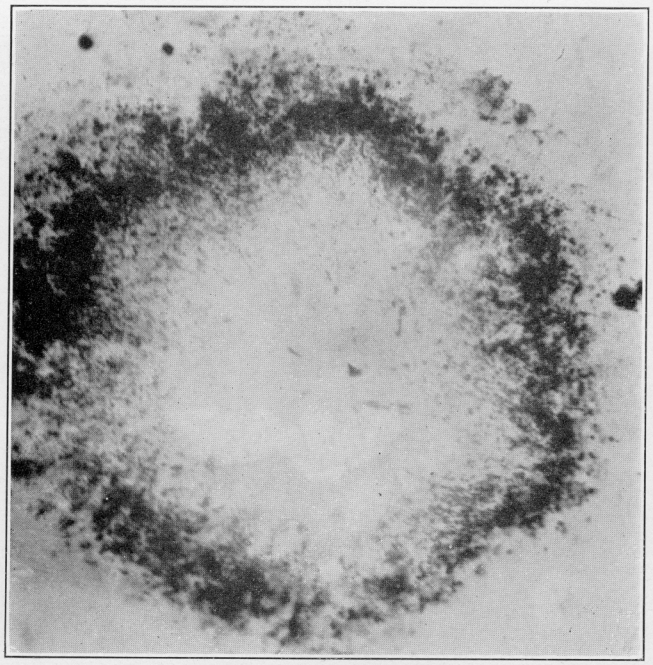
The interstices between quartz crystals in this specimen, though not in most, are filled with carbon. *A*, Crossed nicols; *B*, plain light. Enlarged 86 diameters.



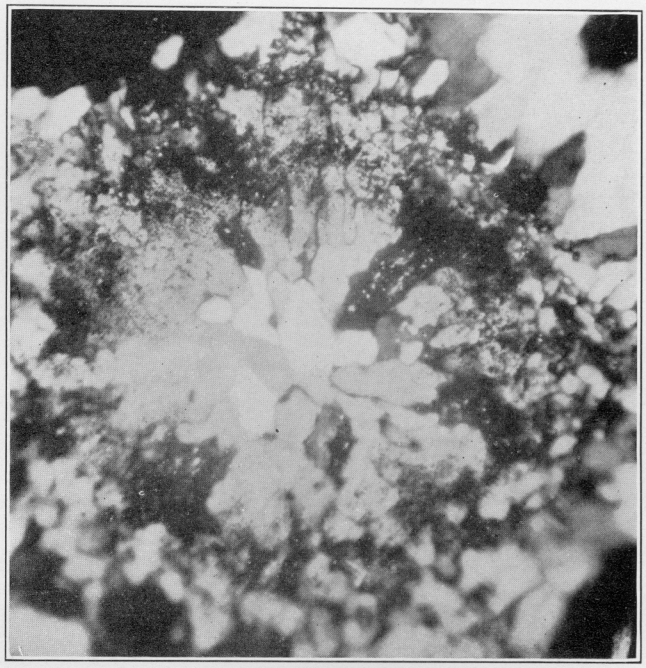
C D

C, D. ANHEDRAL VARIETY OF JASPEROID, VEINED WITH BARITE THAT CONTAINS EUHEDRAL QUARTZ CRYSTALS

C, Crossed nicols; *D*, plain light. q, Quartz; b, barite. Enlarged 81 diameters.



A

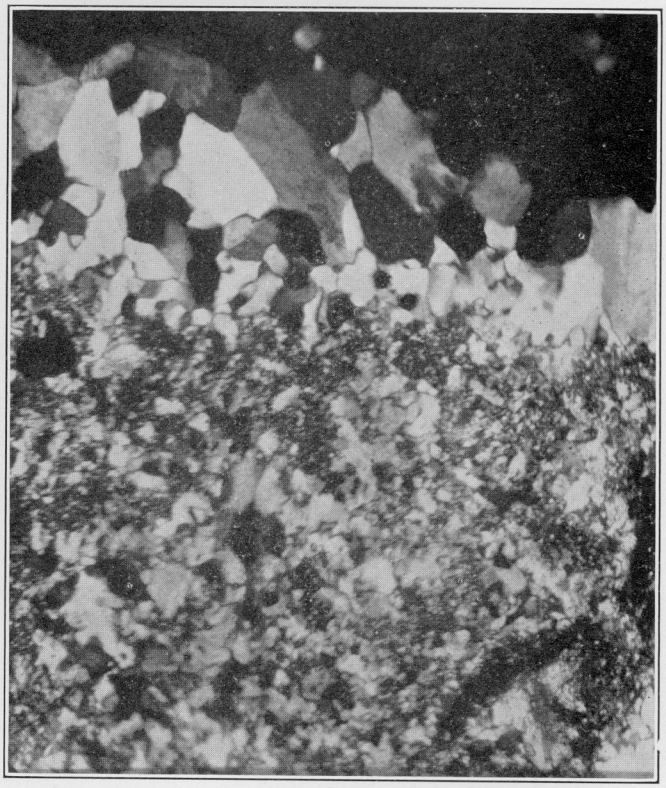


B

A, B. BASAL SECTION OF EUHEDRAL QUARTZ CRYSTAL OUTLINED BY CARBON

A, Plain light; B, crossed nicols. In B the independence of older crystal boundaries shown by the small quartz crystals making up the former euhedral crystal is obvious. Enlarged 200 diameters.

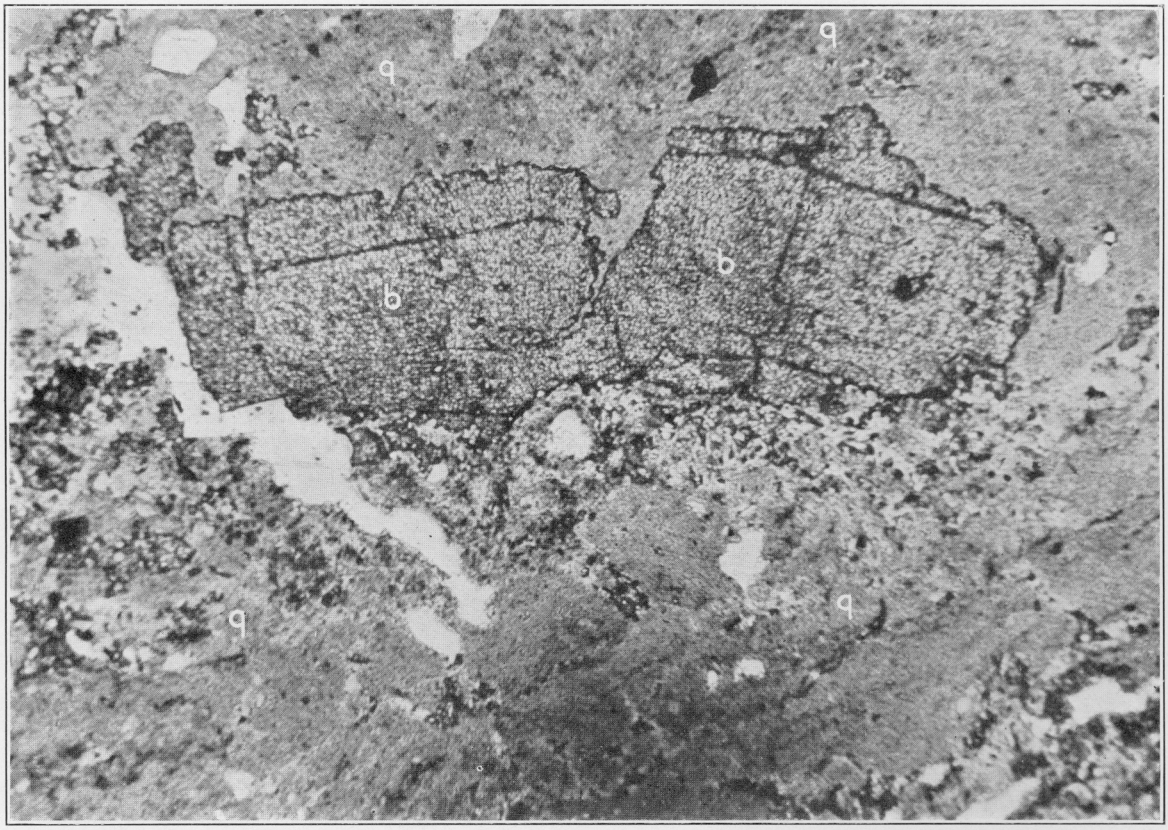
C



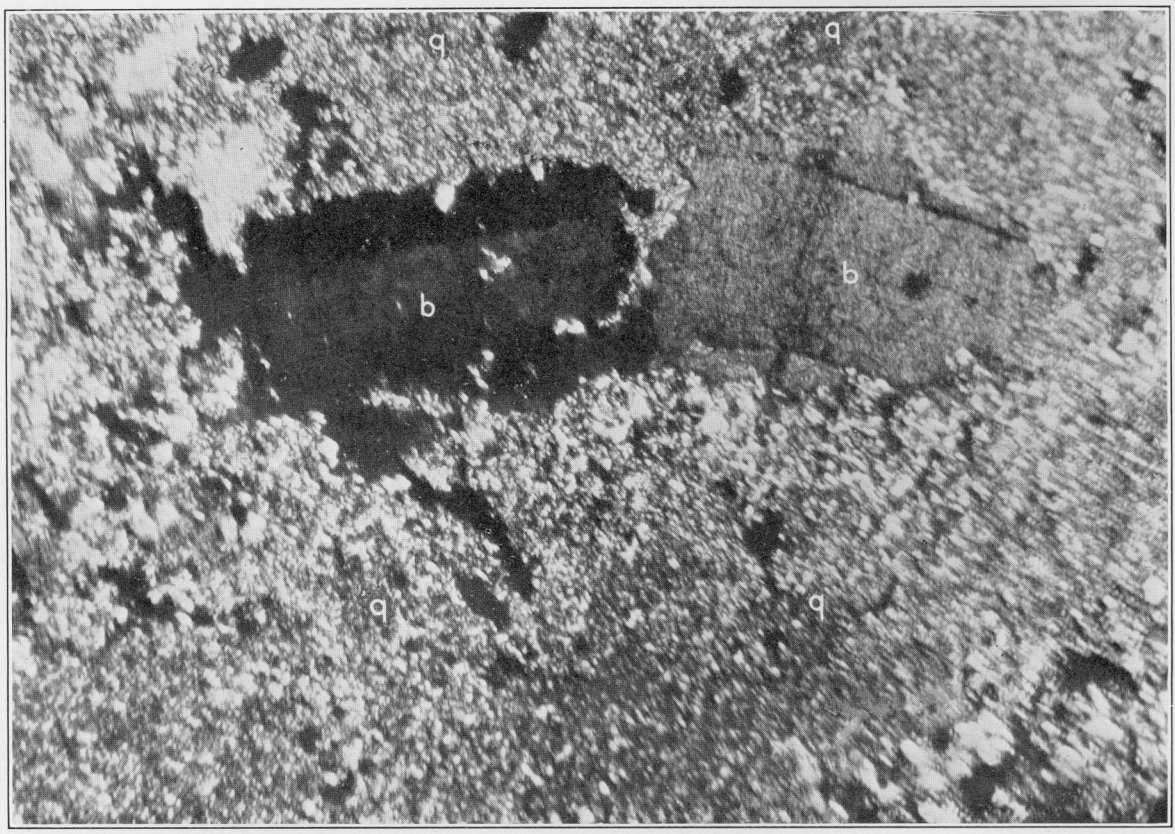
D

C, D. QUARTZ SHOWING "GHOSTS" OF SPHERULES

C, Plain light; D, crossed nicols. In D the spherules are invisible. Enlarged 81 diameters.



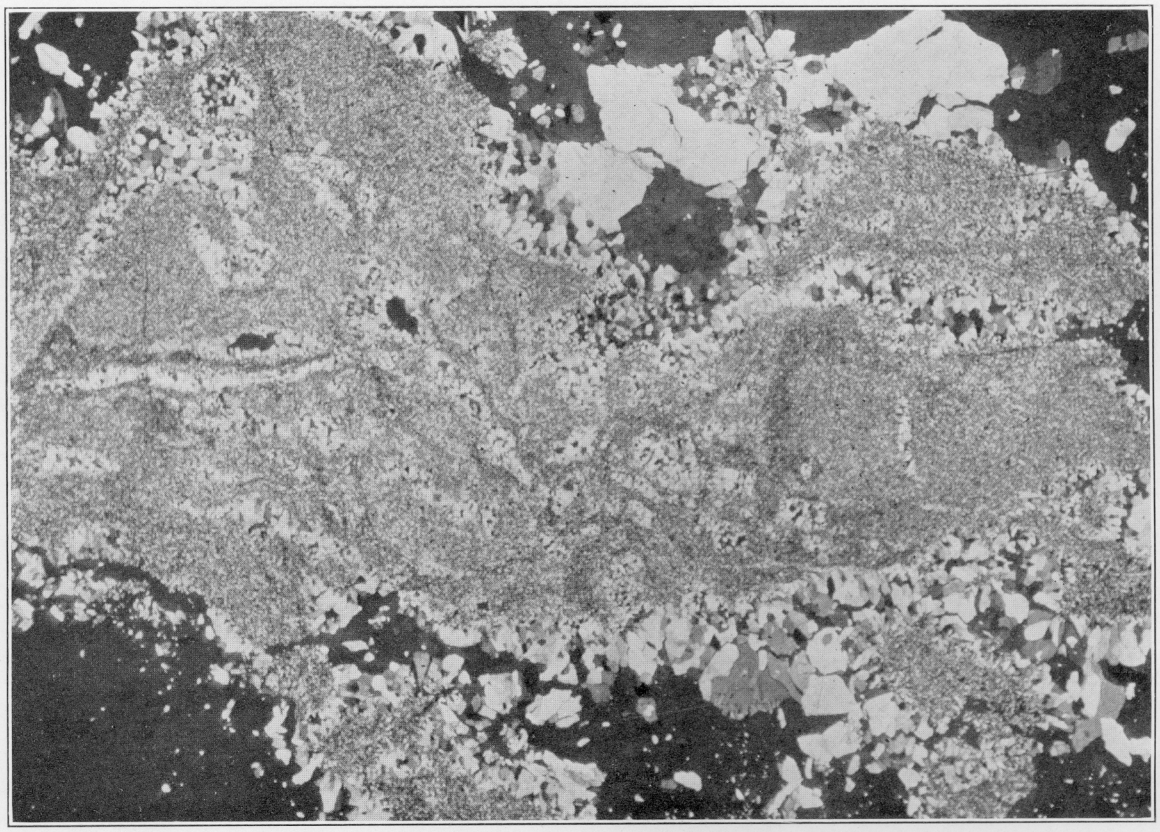
A



B

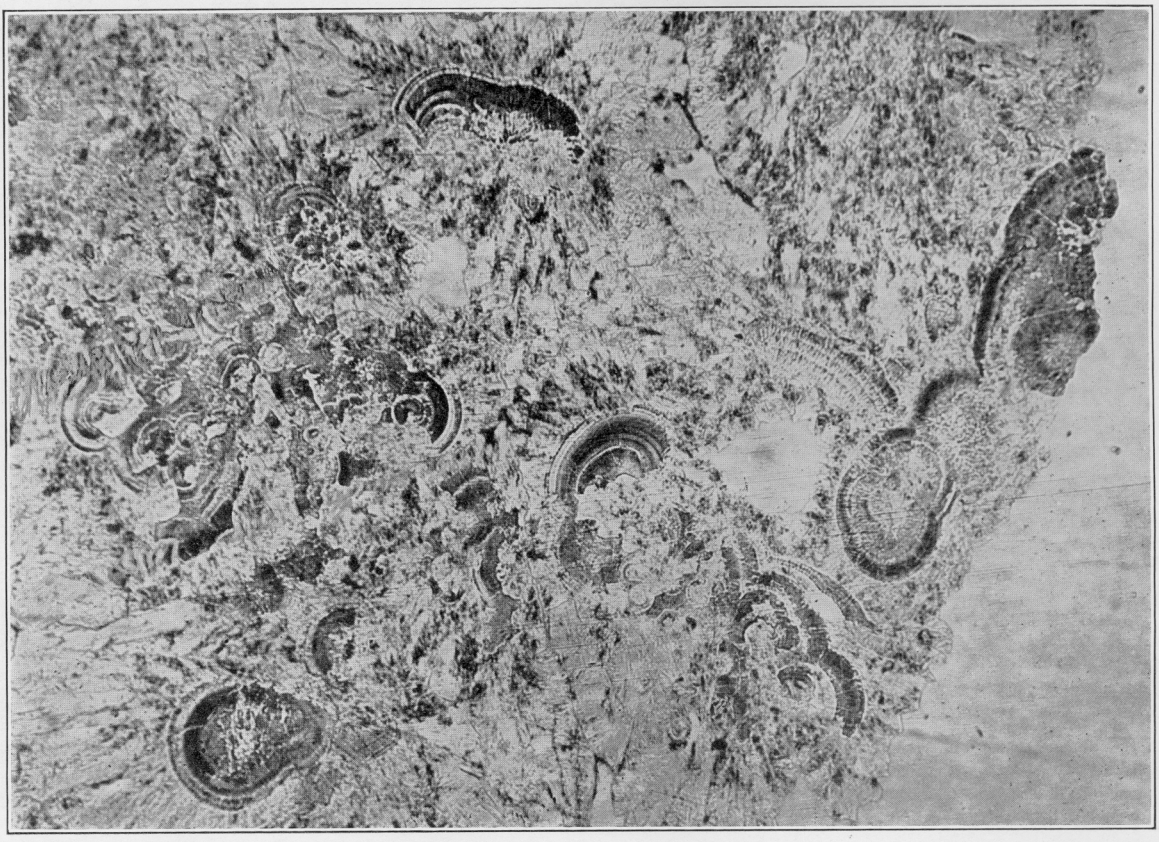
BRECCIATED BARITE PLATE IN MATRIX OF FINE ANHEDRAL QUARTZ WHICH SHOWS NO BRECCIATION AND REPLACES AND IS EUHEDRAL IN DETAIL AGAINST THE BARITE

A, Plain light; *B*, crossed nicols. b, Barite; q, quartz. Enlarged 28 diameters.



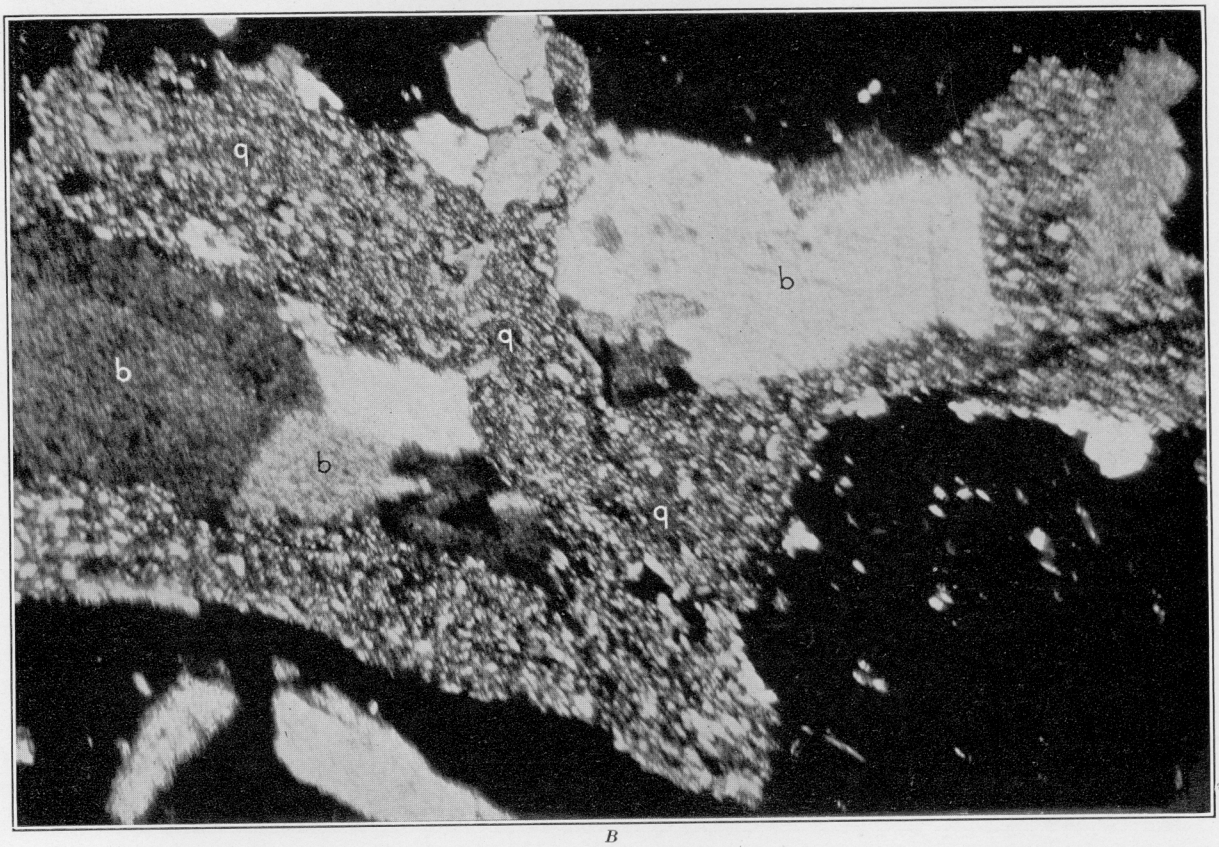
A. FINE-GRAINED ANHEDRAL QUARTZ BRECCIATED AND VEINED WITH COARSELY CRYSTALLINE QUARTZ

The quartz in the vugs is of the flamboyant variety. Crossed nicols. Enlarged 9 diameters.



B. COLLOFORM STRUCTURES IN CHALCEDONY, MERCUR JASPEROID

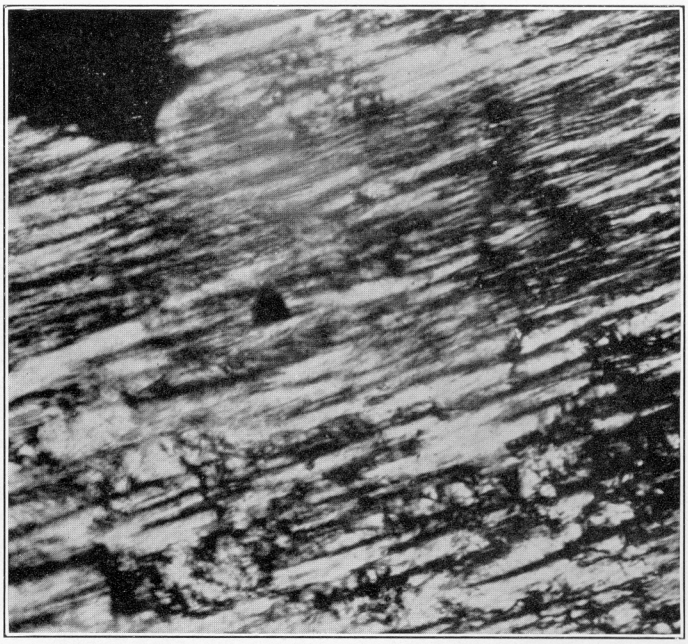
A



B

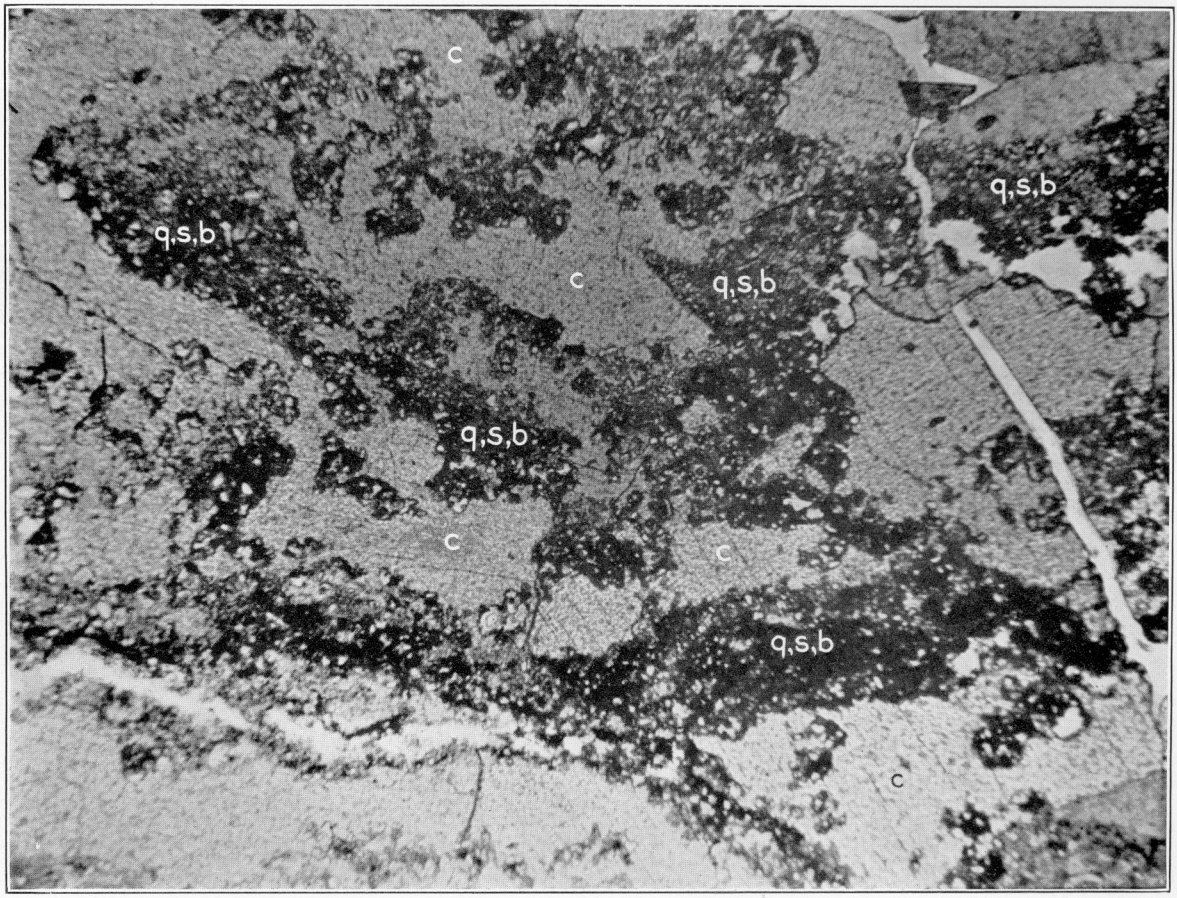
THIRD-GENERATION QUARTZ SHOWING FLOW LINES ALONG BOUNDARIES OF CRACKS IN BARITE WHICH IT IS PENETRATING AND IN PART REPLACING

A, Plain light; *B*, crossed nicols. q, Quartz; b, barite. Enlarged 28 diameters.



A. QUARTZ SHOWING STRAIN TWINNING SUPERFICIALLY RESEMBLING THE TWINNING OF MICROCLINE

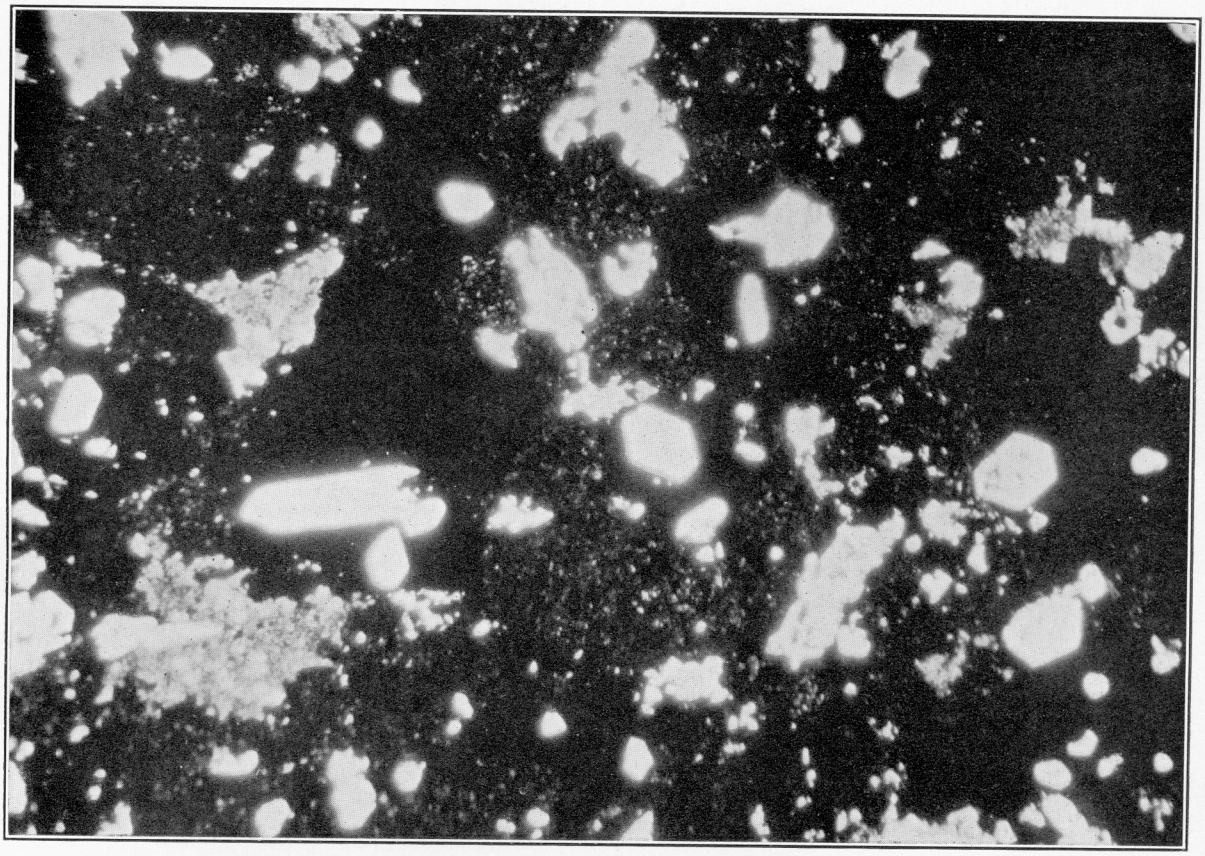
Supposedly due to slight shearing along basal and prism planes. Crossed nicols. Enlarged 500 diameters.



B. CALCITE REPLACED BY STRINGERS OF QUARTZ CARRYING MINUTE SERICITE PLATES AND A LITTLE BARITE

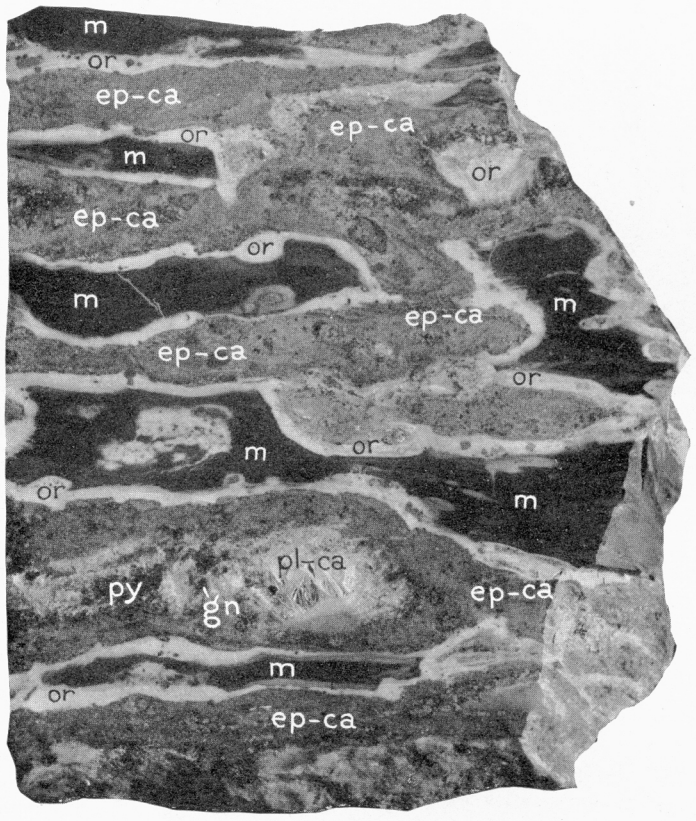
A. LIME HORNFELS, CONSISTING OF CALCITE-RICH, ORTHOCLASE-RICH, AND EPIDOTE-RICH BANDS, PARTLY REPLACED BY PYRRHOTITE

ca, Calcite; py, pyrite; ep, epidote; or, orthoclase; q, quartz. Natural size.



B. PHOTOMICROGRAPH OF HORNFELS ORE SHOWING TENDENCY OF SULPHIDES TO BE MOLDED ON THE EUHEDRAL QUARTZ CRYSTALS

Plain light. Enlarged 65 diameters

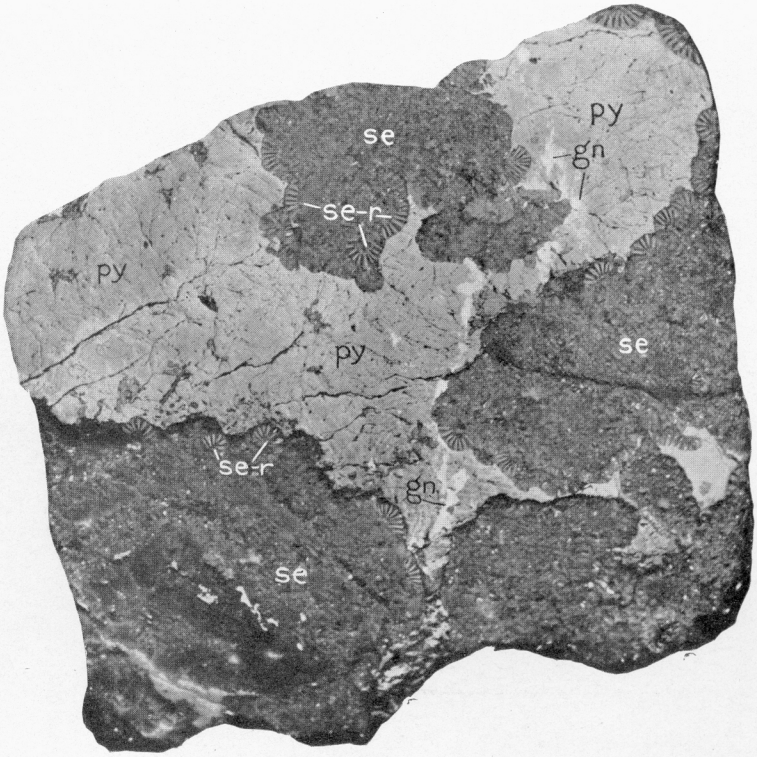


A. HAND SPECIMEN OF BANDED HORNFELS

Consisting of brownish-gray muscovite layers (m) bordered on both sides by nearly pure orthoclase layers (or), with epidote-calcite layers (ep-ca) between them. In some places calcite plates (pl-ca) replace the epidote layers. A little pyrite (py) and galena (gn) occur in one of the epidote-calcite layers. Natural size.

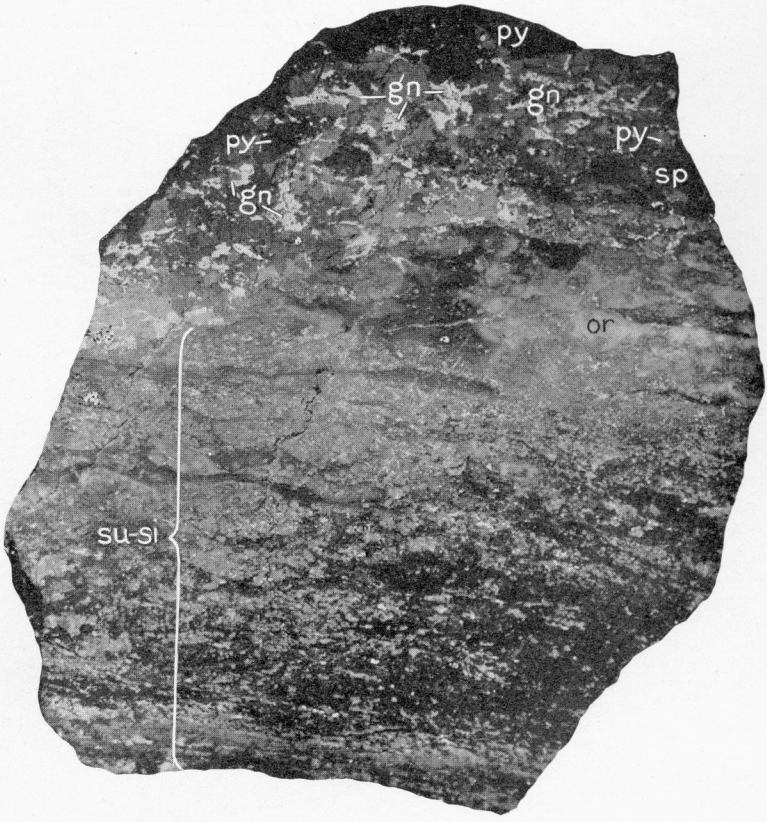
B. HAND SPECIMEN SHOWING VERTICAL FISSURE VEIN CONSISTING OF PYRITE, SPHALERITE, AND GALENA CUTTING CLEANLY THE HORIZONTALLY BANDED HORNFELS

The hornfels itself carries pyrite, galena, and sphalerite of evidently earlier date. Natural size.



A. HAND SPECIMEN SHOWING ROSETTES OF SERICITE (se-r) REPLACING AND INVADING EARLIER PYRITE (py) AND GALENA (gn).

Note radial arrangement of sericite plates about centers. Twice natural size.

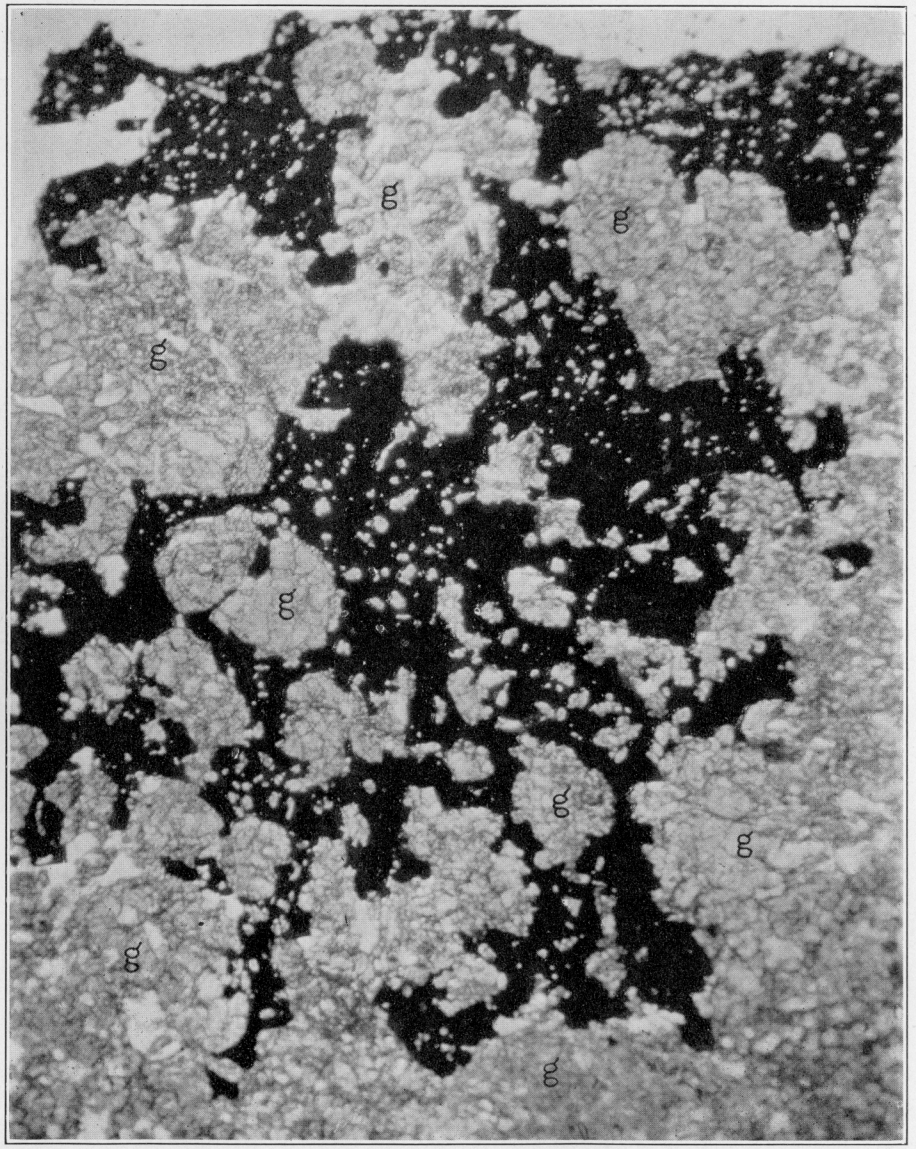


B. SULPHIDE-IMPREGNATED HORNFELS SHOWING BANDING DUE TO SELECTIVE REPLACEMENT OF THE EPIDOTE-CALCITE LAYERS BY PYRITE (py), SPHALERITE (sp), AND GALENA (gn)

Muscovite and orthoclase-quartz layers of the original hornfels (su-si) are much less replaced by the sulphides. Hand specimen, natural size.

A. HAND SPECIMEN OF ORE FROM OPHIR HILL MINE

Epidote layers of hornfels largely replaced by pyrite, sphalerite, and galena. The orthoclase (or) and muscovite (m) layers remain essentially unaltered. a, Sulphides, with a little calcite, epidote, and quartz; s, sulphides; or, ep, q, orthoclase, epidote, and quartz; or, orthoclase; a′, mixed sulphides, orthoclase, quartz, and epidote; p, idiomorphic pyrite.

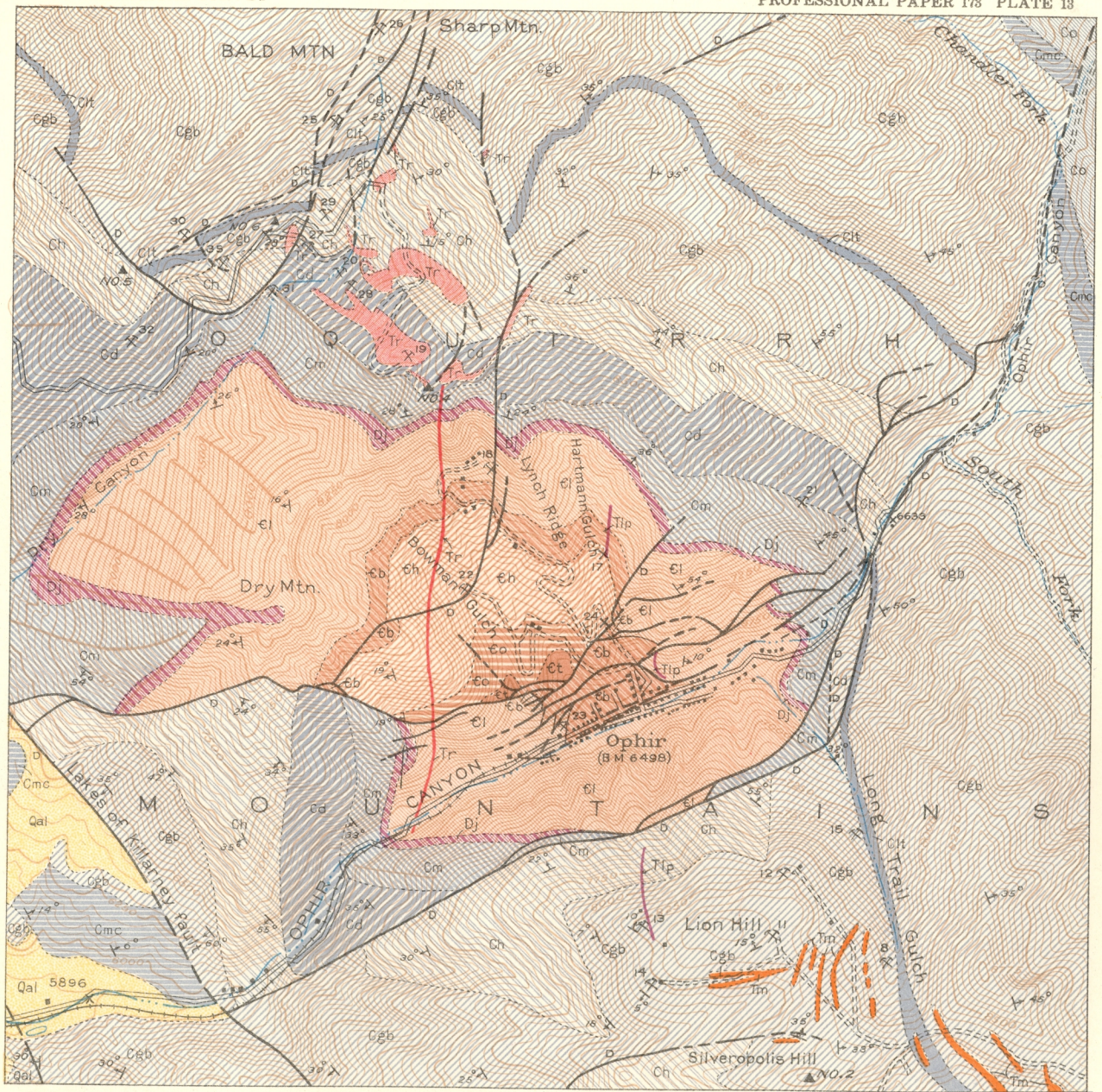


B. GARNET HORNFELS IMPREGNATED AND PARTLY REPLACED BY PYRITE, SPHALERITE, AND GALENA, OPHIR HILL MINE

Black areas, sulphides; g, garnet. Plain light. Enlarged 50 diameters.

HAND SPECIMEN OF DOLOMITE, VEINED AND PARTLY REPLACED BY SULPHIDES, ORTHOCLASE, AND QUARTZ, OPHIR HILL MINE

Py, Pyrite; cp, chalcopyrite; gn, galena; sp, sphalerite; or, orthoclase; q, quartz. Mass of specimen is dolomite. Natural size.



Base enlarged from U. S. G. S. map of Stockton and Fairfield quadrangles Surveyed in 1915 and 1916

0 1 Mile

Contour interval 50 feet
Datum is mean sea level

Geology by James Gilluly assisted by H. G. Mitchell, W. D. Mark, and M. J. Buerger Surveyed in 1926 and 1927.

EXPLANATION

SEDIMENTARY ROCKS

- Qal — Alluvium — *Pleistocene and Recent* — QUATERNARY
- UNCONFORMITY
- Co — Oquirrh formation — *Pennsylvanian*
- Cmc — Manning Canyon shale — *Pennsylvanian*
- Cgb / Clt — "Great Blue" limestone (*with Long Trail shale member, Clt, about 500 feet above the base*) — *Upper Mississippian*
- Ch — Humbug formation — *Upper Mississippian*
- Cd — Deseret limestone — *Upper Mississippian*
- Cm — Madison limestone — *Lower Mississippian* — CARBONIFEROUS
- UNCONFORMITY
- Dj — Jefferson (?) dolomite — *Middle(?) Devonian* — DEVONIAN
- UNCONFORMITY
- €l — Lynch dolomite — *Upper Cambrian*
- €b — Bowman limestone — *Middle Cambrian*
- €h — Hartmann limestone — *Middle Cambrian*
- €o — Ophir formation — *Lower Cambrian*
- €t — Tintic quartzite — *Lower Cambrian* — CAMBRIAN

IGNEOUS ROCKS (*Intrusive*)

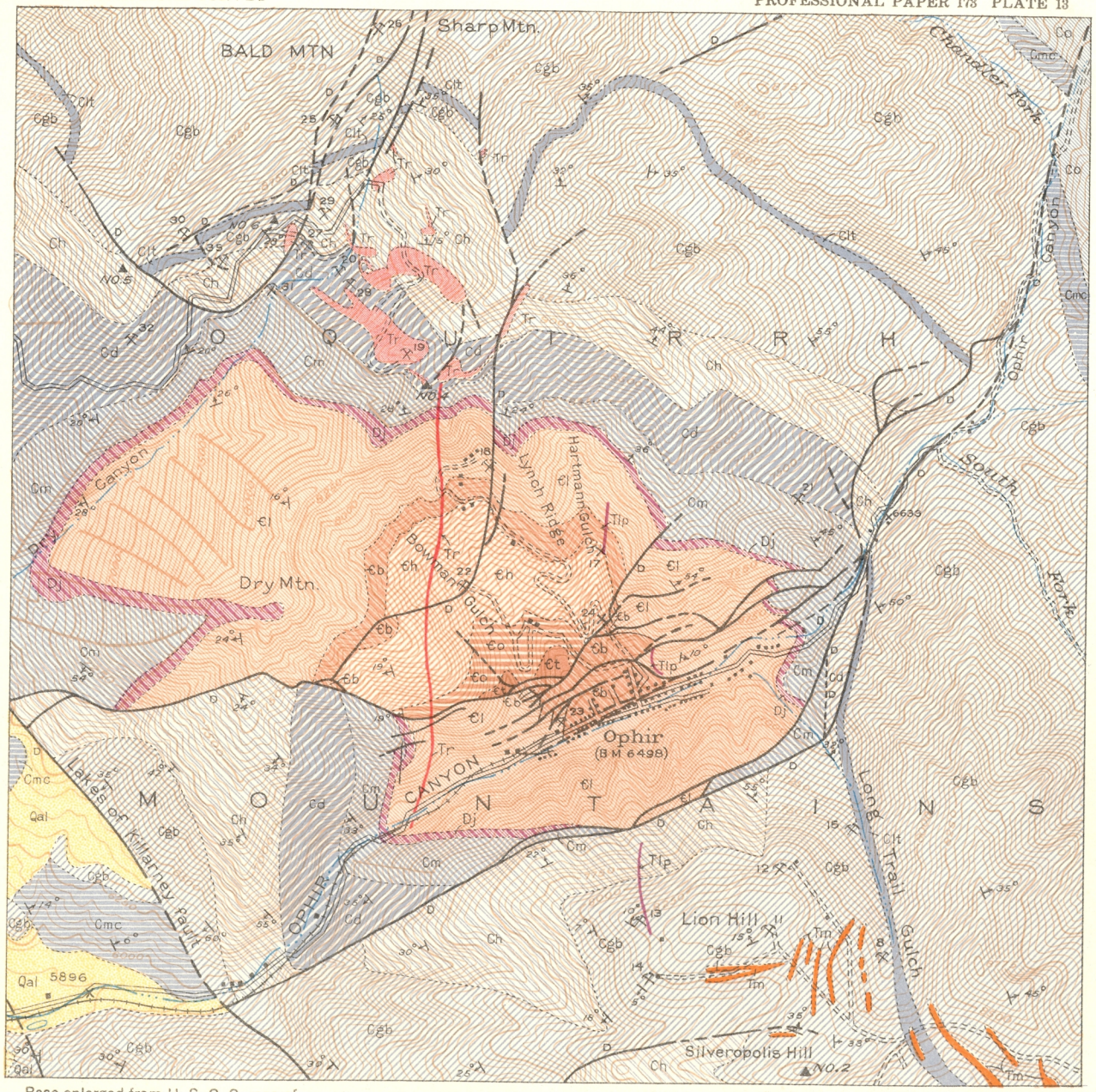
Eocene (?)

- Tlp — Lamprophyre (*kersantite*)
- Tr — Rhyolite (*including Eagle Hill rhyolite, Shaggy Peak rhyolite, and Tickville rhyolite*)
- Tm — Monzonite, monzonite porphyry, and related rocks (*including "Birdseye" porphyry*)

- D — Fault (D, *downthrown side*)
- Fault (*Location approximate*)
- Strike and dip
- Mine (*See list of mines on areal geologic map*)
- Prospect
- U. S. mineral monument

DETAILED GEOLOGIC MAP OF OPHIR AND DRY CANYONS, OQUIRRH RANGE, UTAH

1932



Base enlarged from U. S. G. S. map of Stockton and Fairfield quadrangles Surveyed in 1915 and 1916

Geology by James Gilluly assisted by H. G. Mitchell, W. D. Mark, and M. J. Buerger Surveyed in 1926 and 1927.

EXPLANATION

SEDIMENTARY ROCKS

- Pleistocene and Recent — QUATERNARY
  - Qal — Alluvium
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- Pennsylvanian — CARBONIFEROUS
  - Co — Oquirrh formation
  - Cmc — Manning Canyon shale
- Upper Mississippian — CARBONIFEROUS
  - Cgb / Clt — "Great Blue" limestone (with Long Trail shale member, Clt, about 500 feet above the base)
  - Ch — Humbug formation
  - Cd — Deseret limestone
- Lower Mississipp. — CARBONIFEROUS
  - Cm — Madison limestone
- UNCONFORMITY
- Middle(?) Devonian — DEVONIAN
  - Dj — Jefferson (?) dolomite
- UNCONFORMITY
- Upper Cambrian — CAMBRIAN
  - €l — Lynch dolomite
- Middle Cambrian — CAMBRIAN
  - €b — Bowman limestone
  - €h — Hartmann limestone
- Lower Cambrian — CAMBRIAN
  - €o — Ophir formation
  - €t — Tintic quartzite

IGNEOUS ROCKS (Intrusive)

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  - Tlp — Lamprophyre (kersantite)
  - Tr — Rhyolite (including Eagle Hill rhyolite, Shaggy Peak rhyolite, and Tickville rhyolite)
  - Tm — Monzonite, monzonite porphyry, and related rocks (including "Birdseye" porphyry)

D — Fault (D, downthrown side)

Fault (Location approximate)

Strike and dip

Mine (See list of mines on areal geologic map)

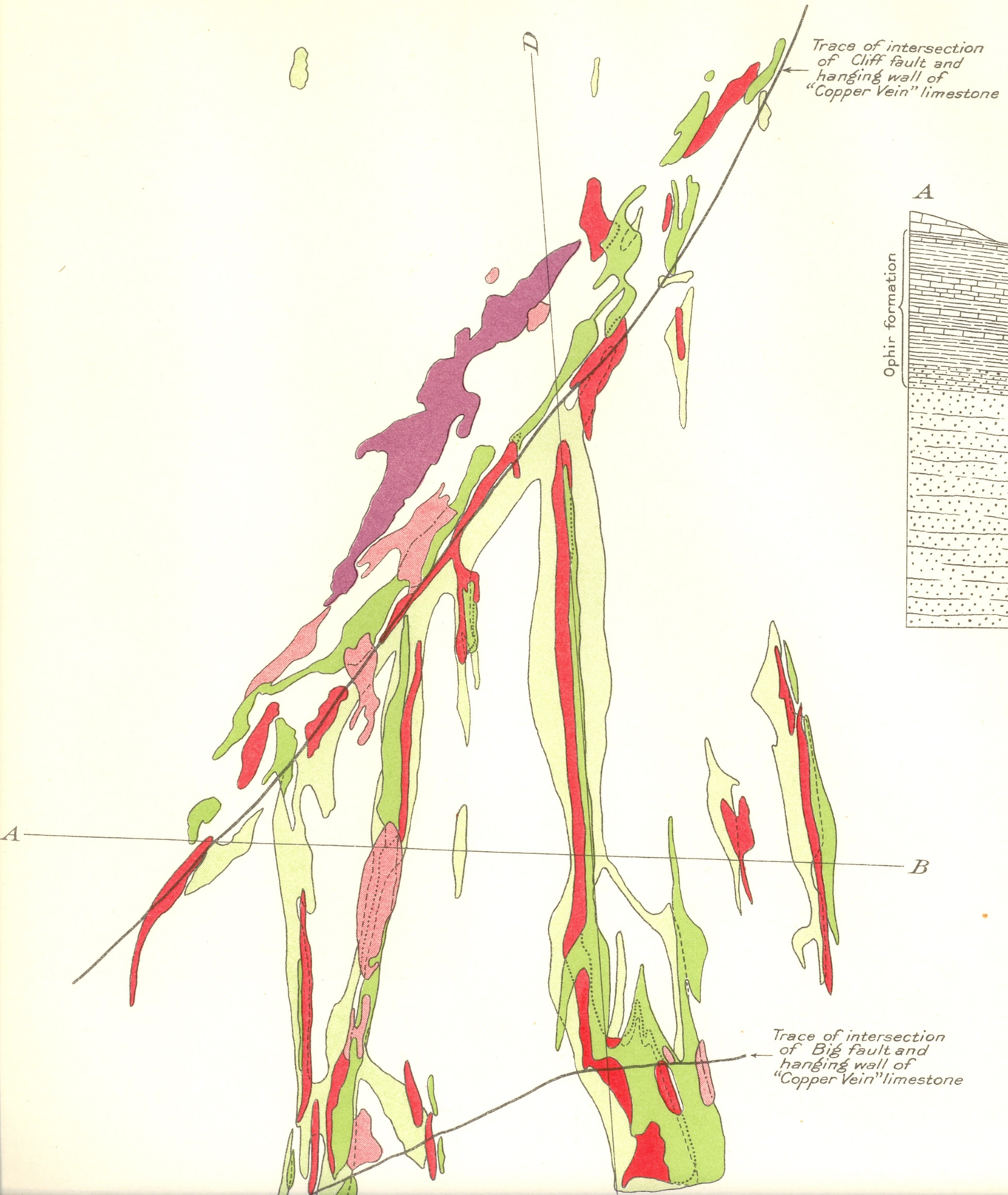
Prospect

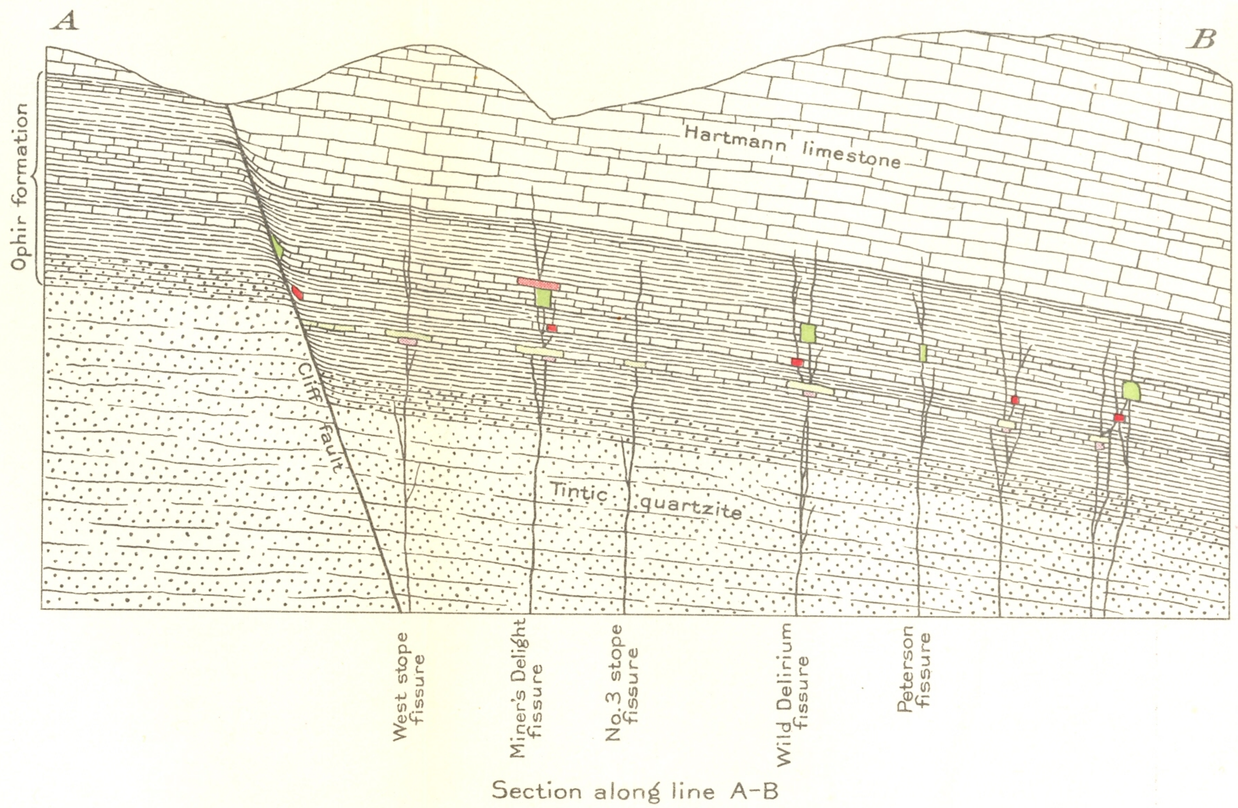
U. S. mineral monument

DETAILED GEOLOGIC MAP OF OPHIR AND DRY CANYONS, OQUIRRH RANGE, UTAH

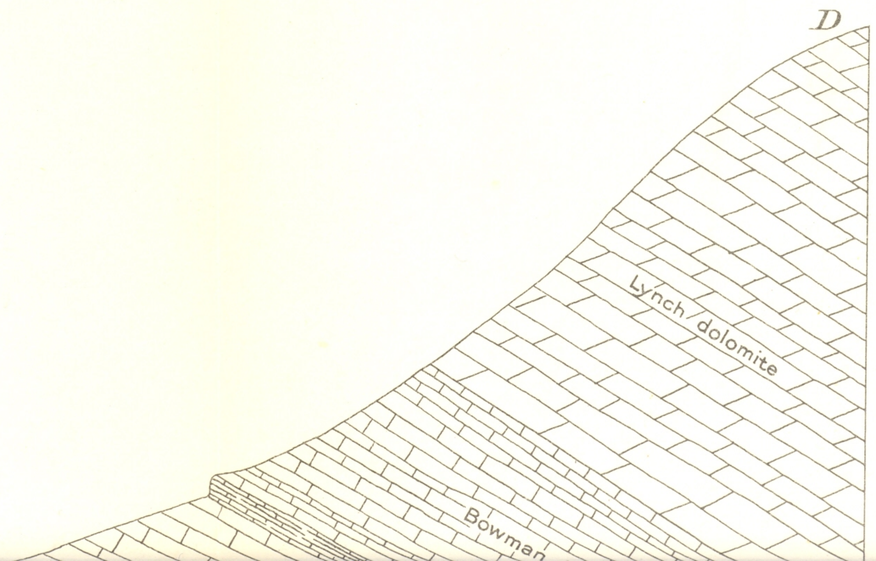
1932

MAP SHOWING WORKINGS OF THE CLIFF, HIDDEN TREASURE, SACRAMENTO, AND CHICAGO MINES, OPHIR DISTRICT





Section along line A-B



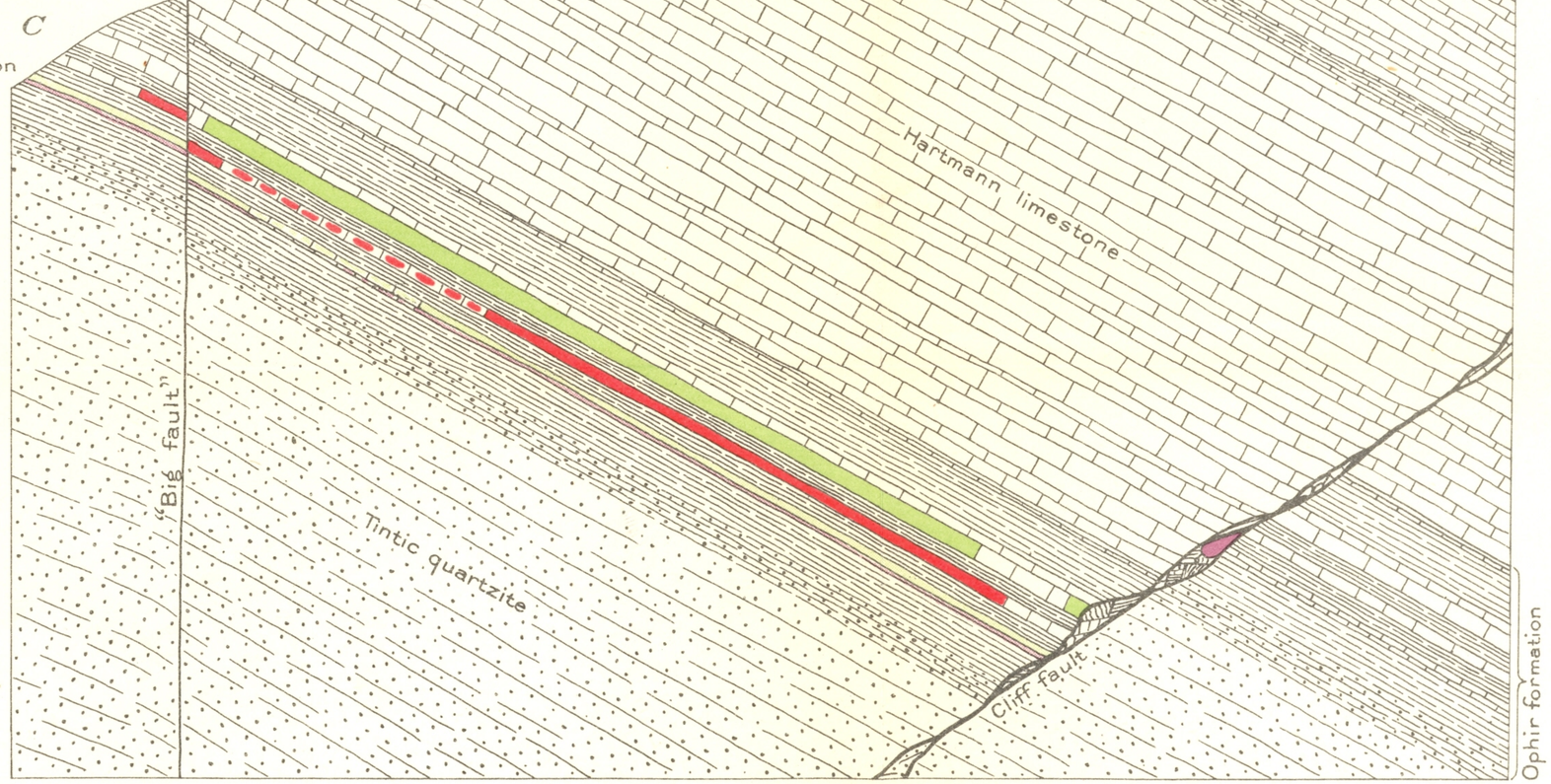
STOPES

- "Top" bed
- "Big" bed
- "Middle" bed
- "Copper Vein" bed
- "Blue Vein" bed
- Fault block, unknown horizon

CONCEALED BOUNDARIES

- "Big" bed
- "Middle" bed
- "Copper Vein" bed

Section along line A–B



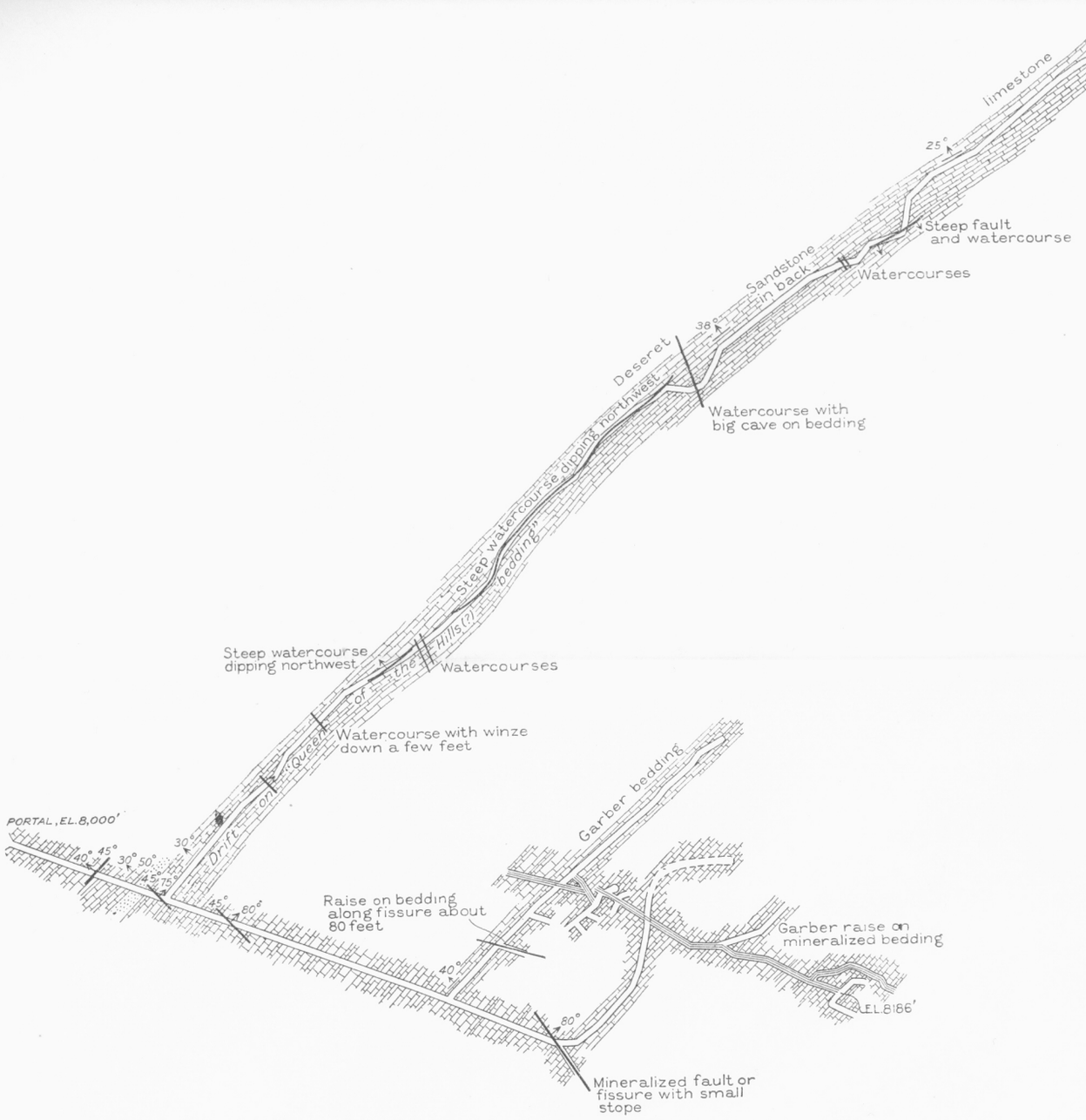
Section along line C–D

STOPE MAP AND SECTIONS OF ORE BODIES OF THE OPHIR HILL CONSOLIDATED MINE, OPHIR DISTRICT, UTAH

Approximate scale

200 0 600 Feet

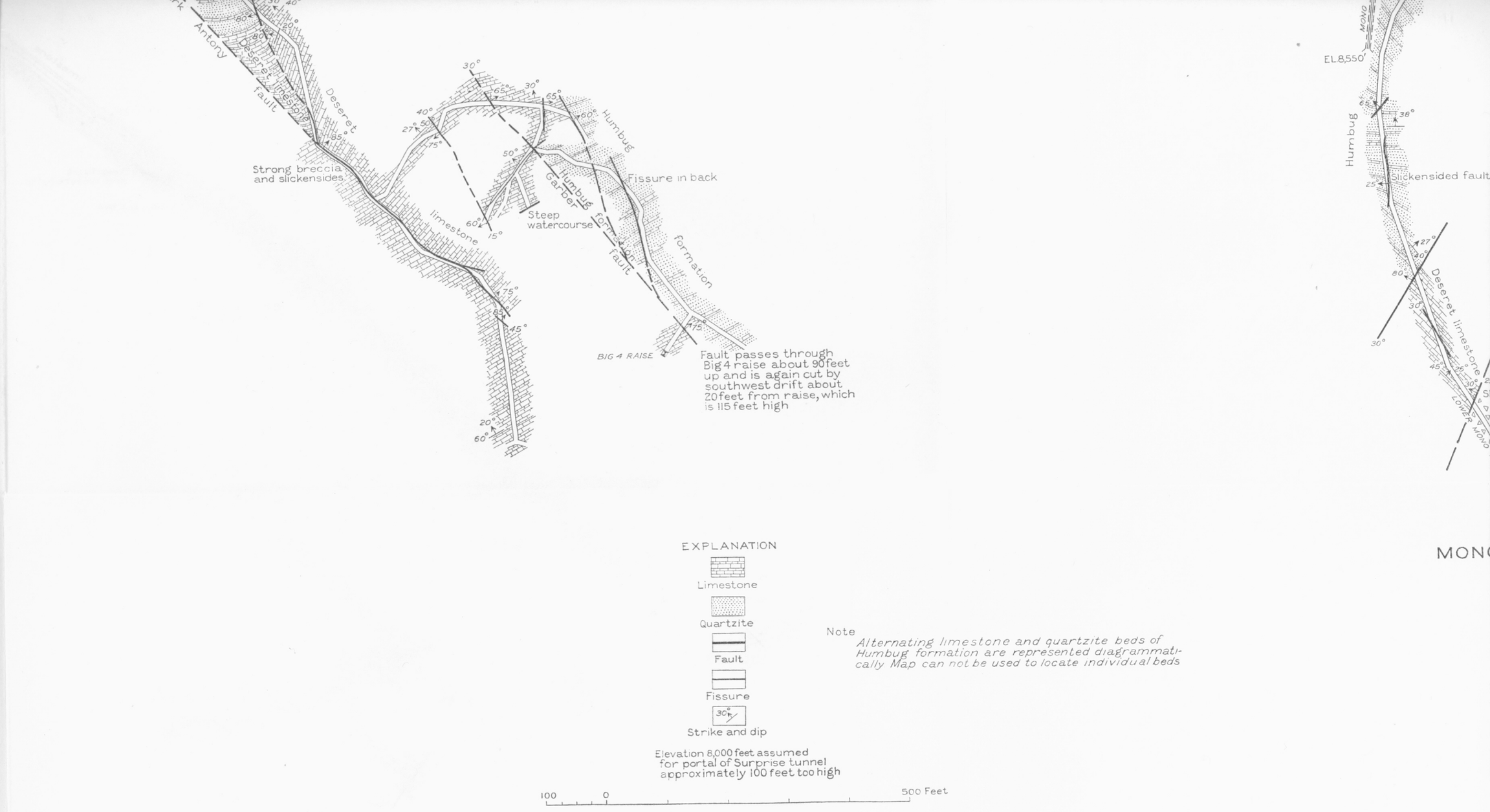
1932



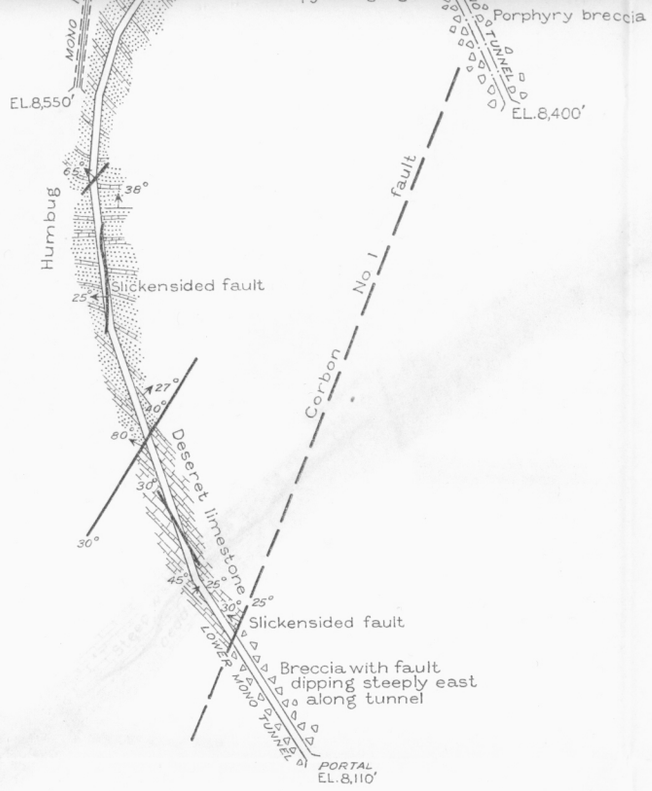
SURPRISE TUNNEL

100

MAP OF THE MO



MAP OF THE MONO MINE AND SURPRISE TUNNEL, DRY CANYON



MONO MINE

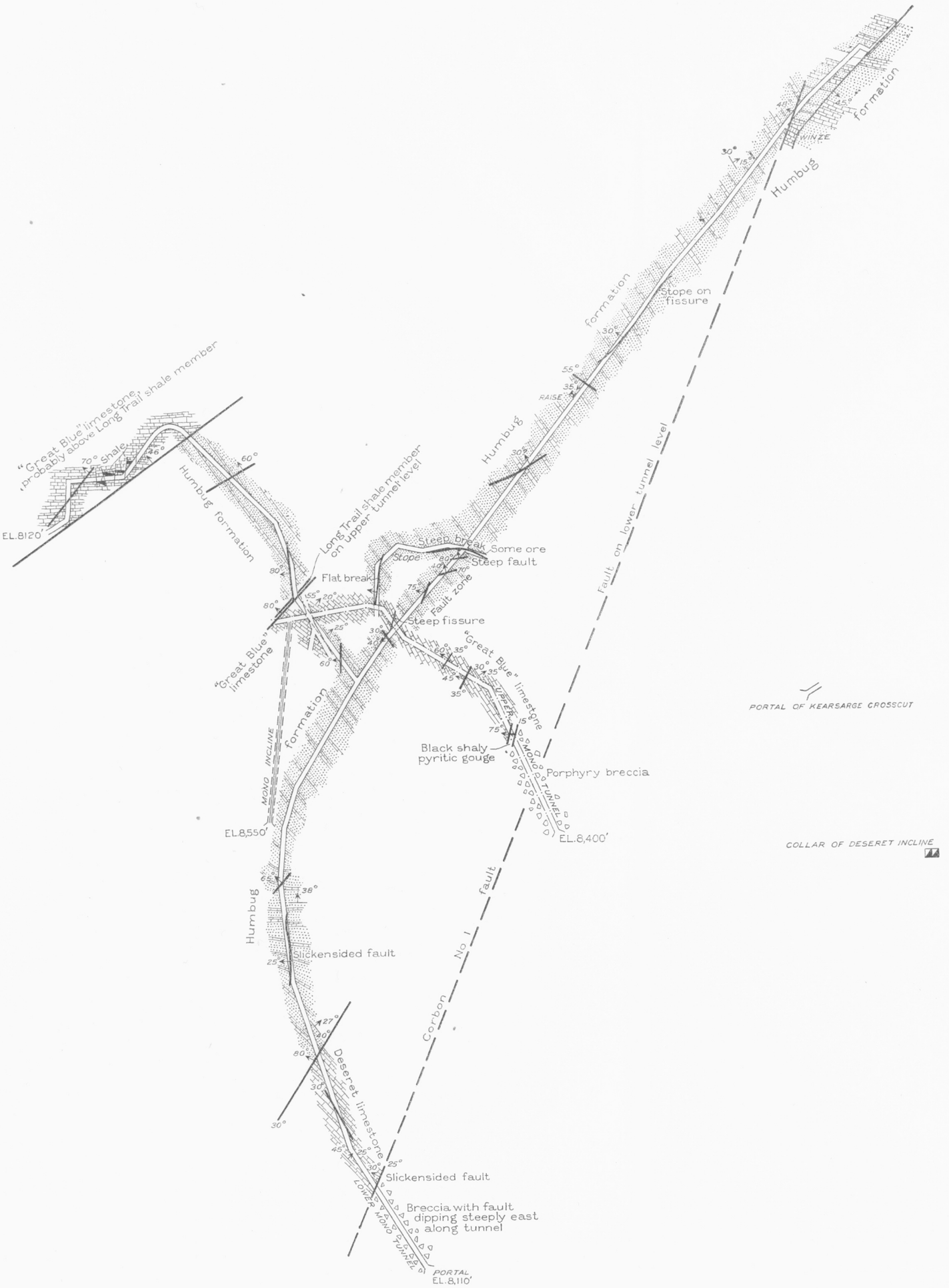
COLLAR OF DESERET INCLINE

PORTAL OF HIDDEN TREASURE TUNNEL

mestone and quartzite beds of
ation are represented diagrammati-
not be used to locate individual beds

WANDERING JEW INCLINE

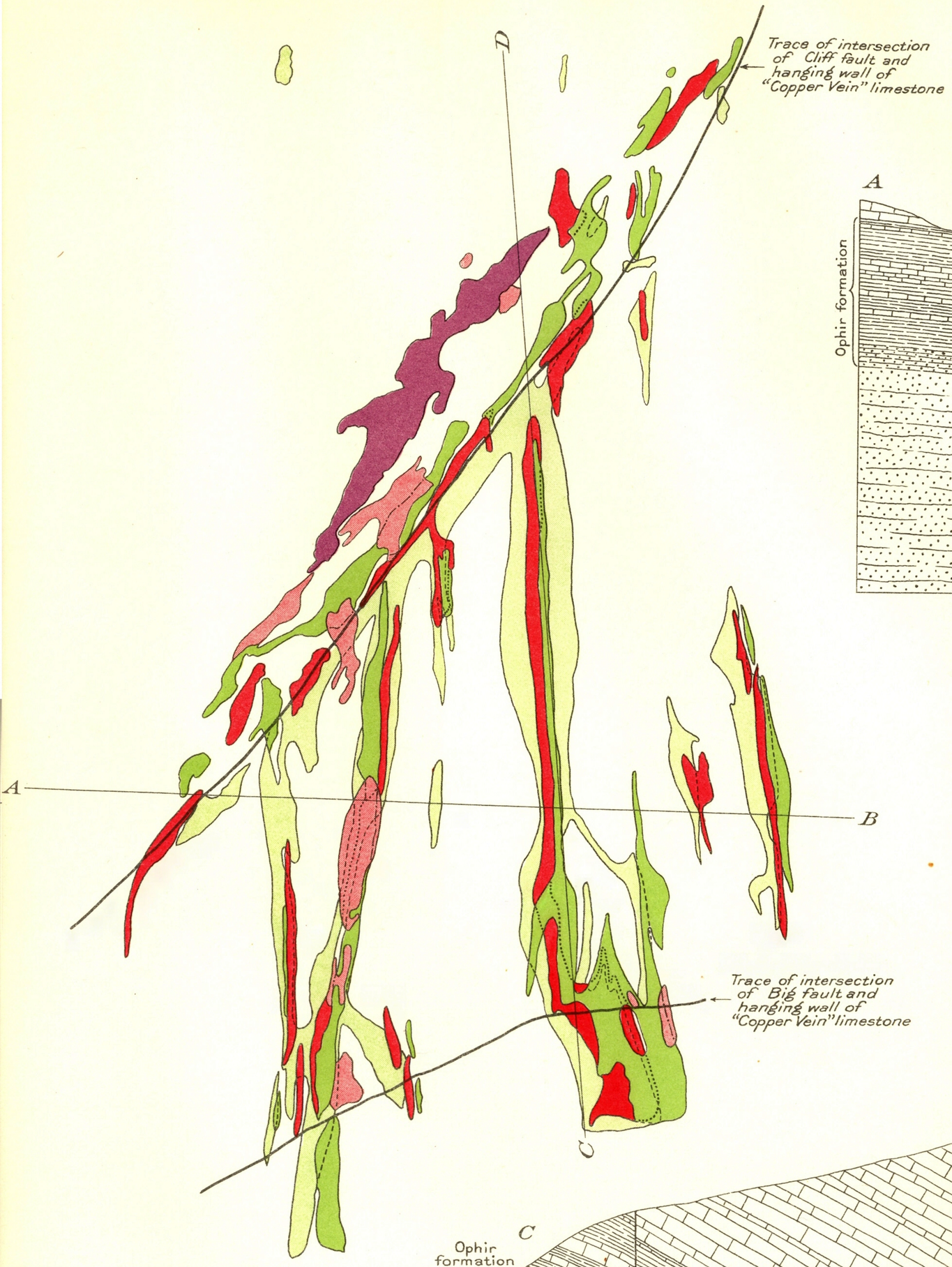
SURPRISE TUNNEL



MONO MINE

d quartzite beds of
esented diagrammati-

MAP SHOWING WORKINGS OF THE CLIFF, HIDDEN TREASURE, SACRAMENTO, AND CHICAGO MINES, OPHIR DISTRICT

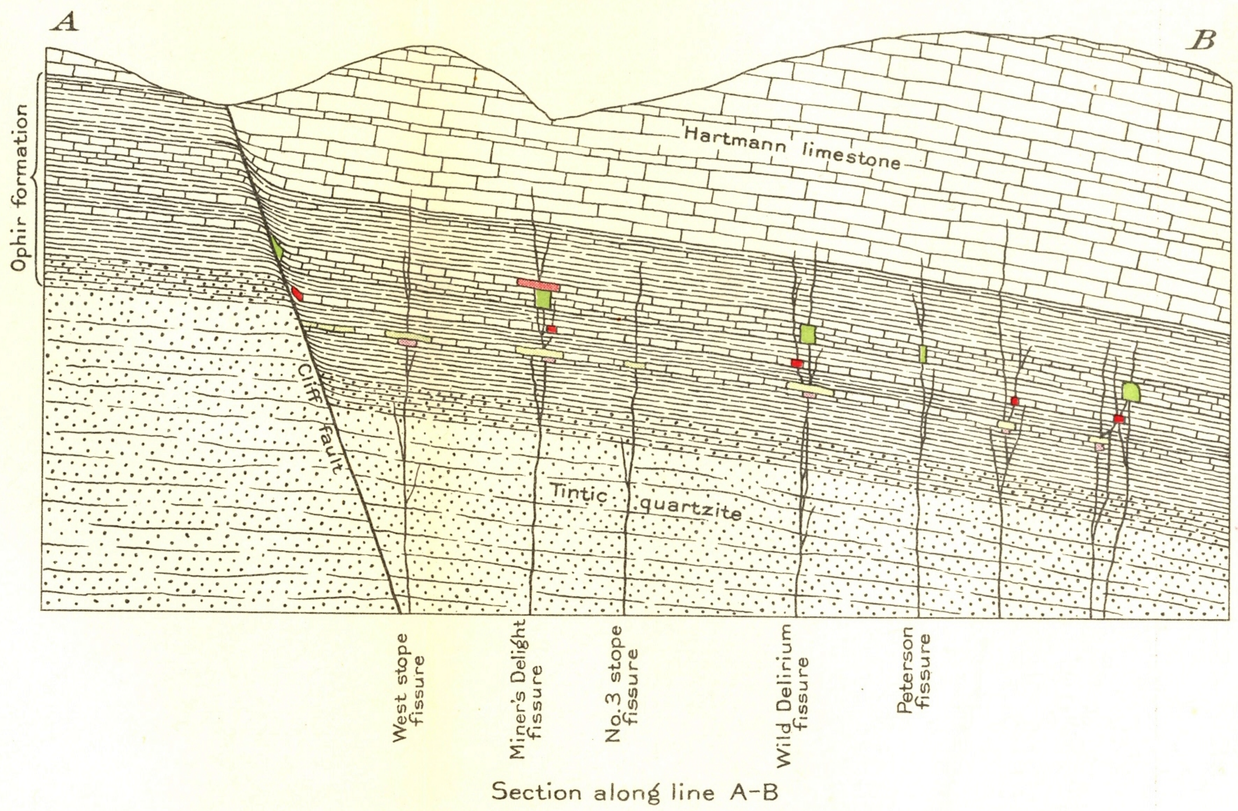


STOPES

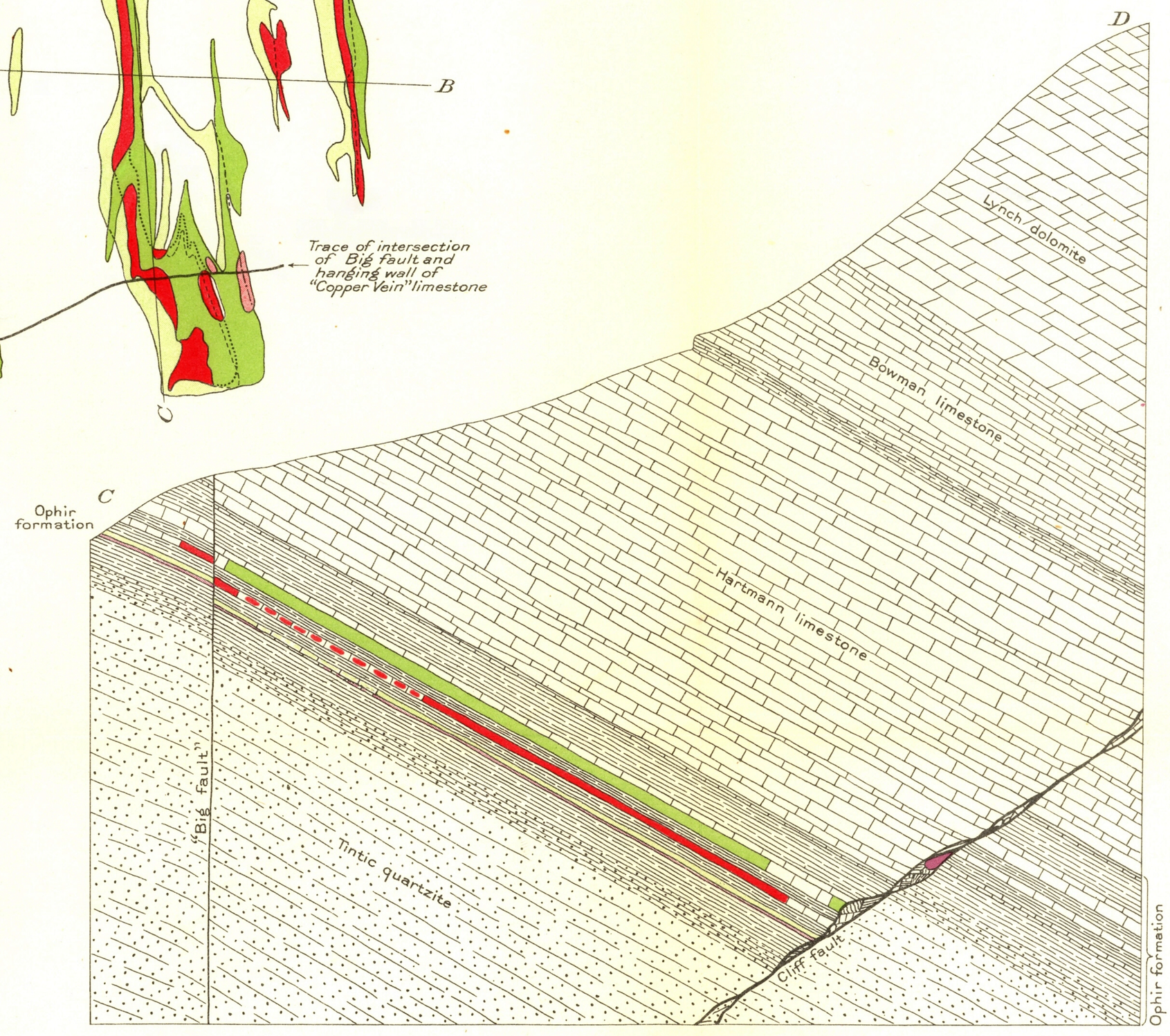
- "Top" bed
- "Big" bed
- "Middle" bed
- "Copper Vein" bed
- "Blue Vein" bed
- Fault block, unknown horizon

CONCEALED BOUNDARIES

- "Big" bed
- "Middle" bed
- "Copper Vein" bed



Section along line A–B



Section along line C–D

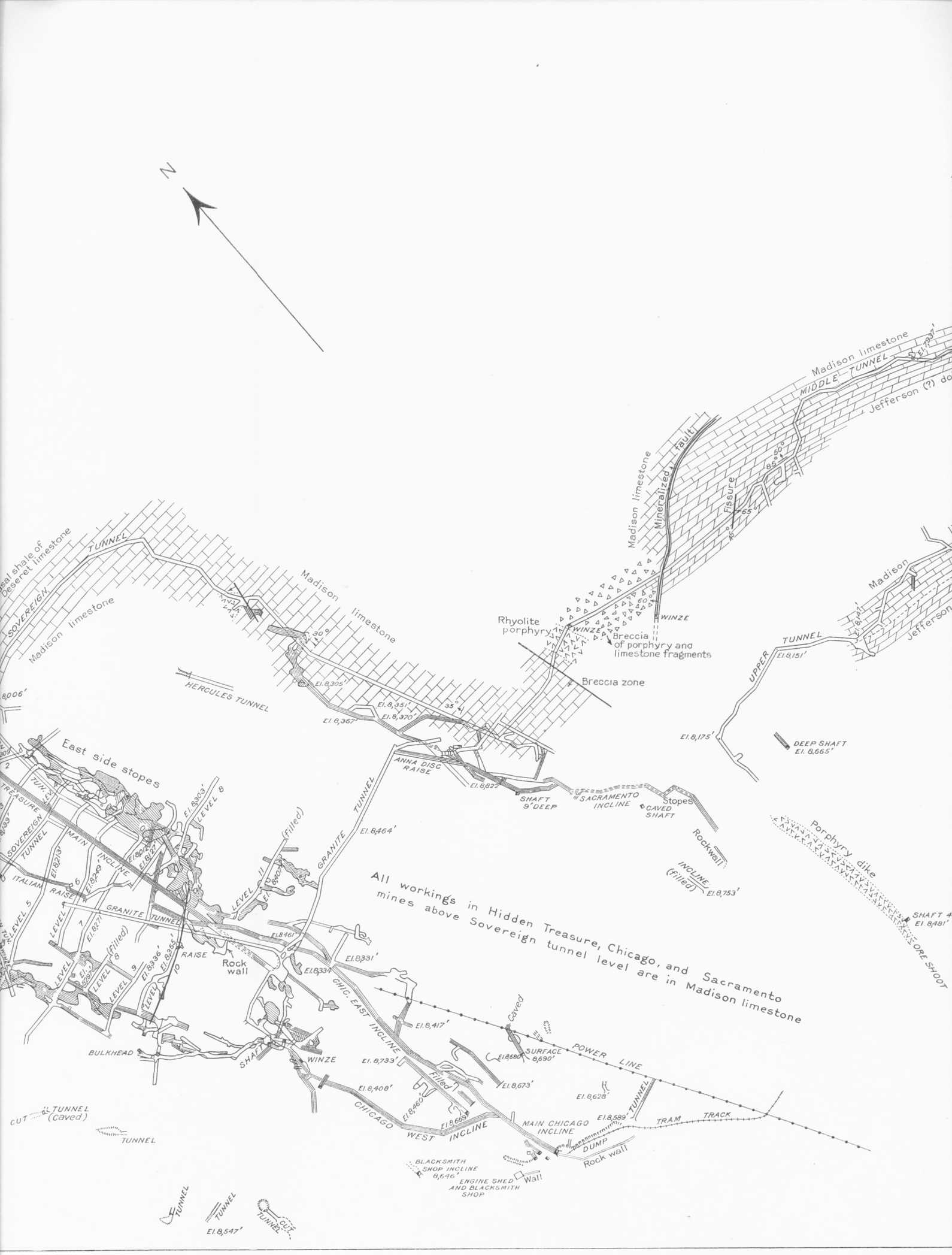
STOPE MAP AND SECTIONS OF ORE BODIES OF THE OPHIR HILL CONSOLIDATED MINE, OPHIR DISTRICT, UTAH

Approximate scale

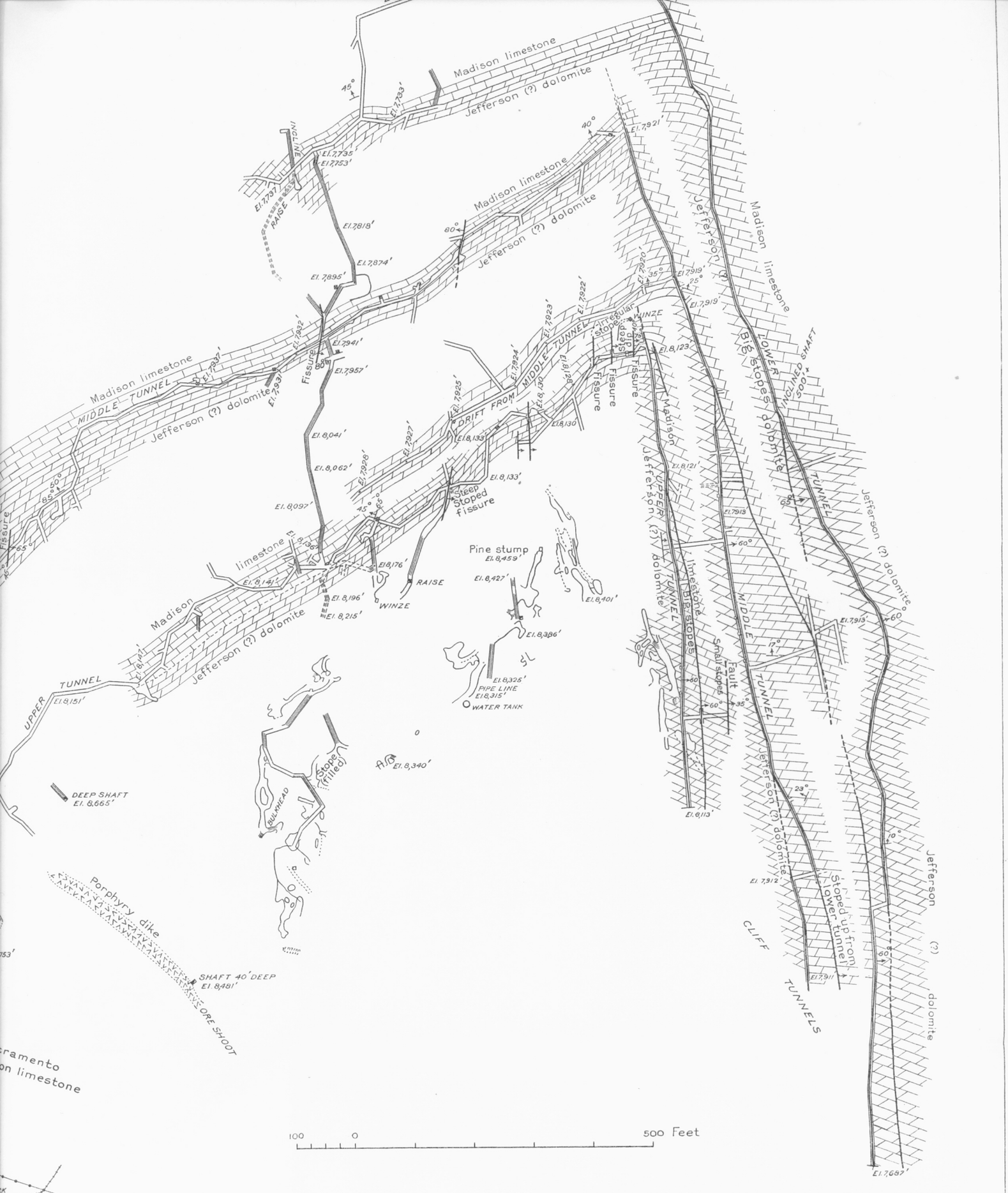
200 0 600 Feet

1932

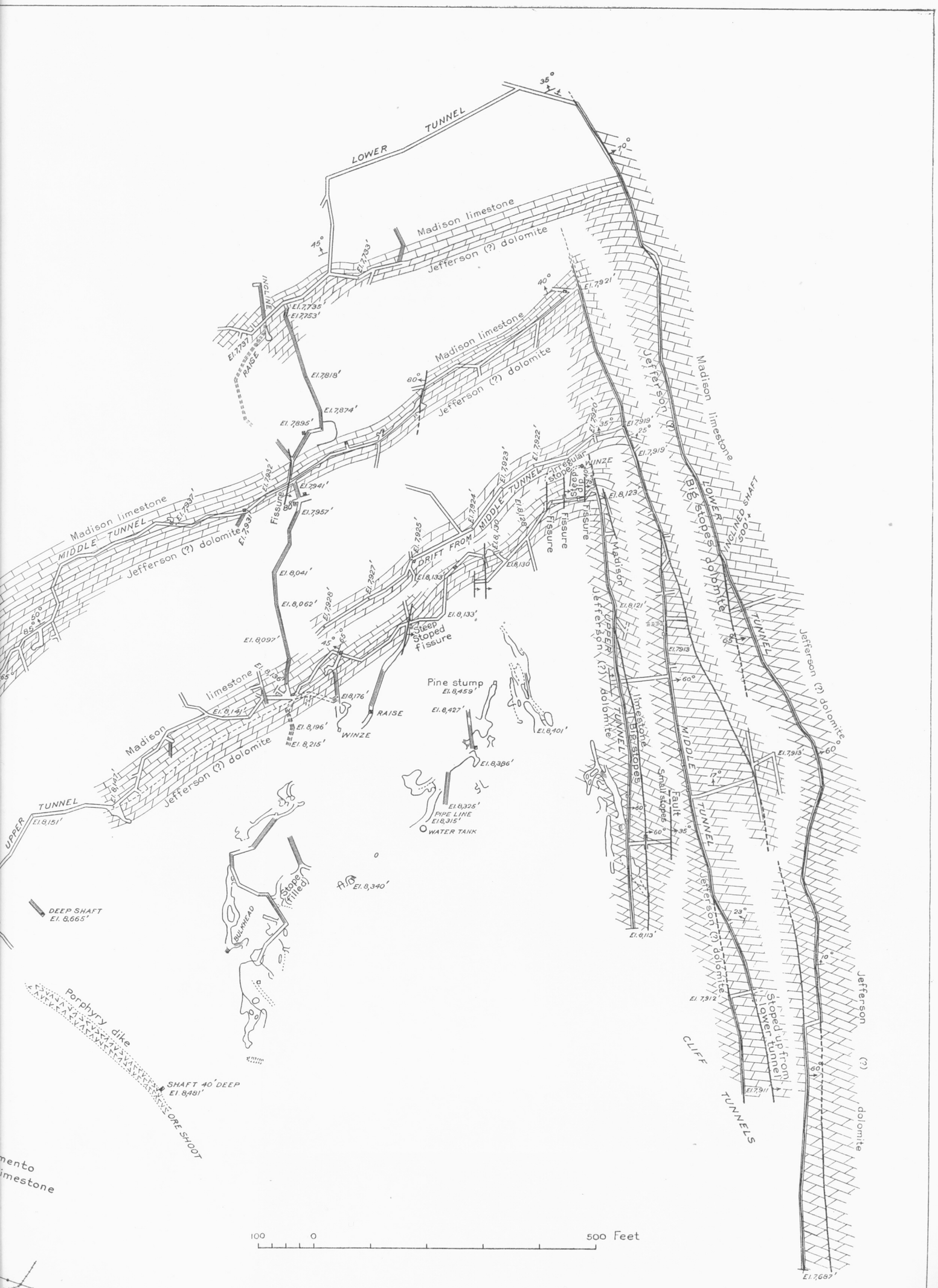
MAP SHOWING WORKINGS OF

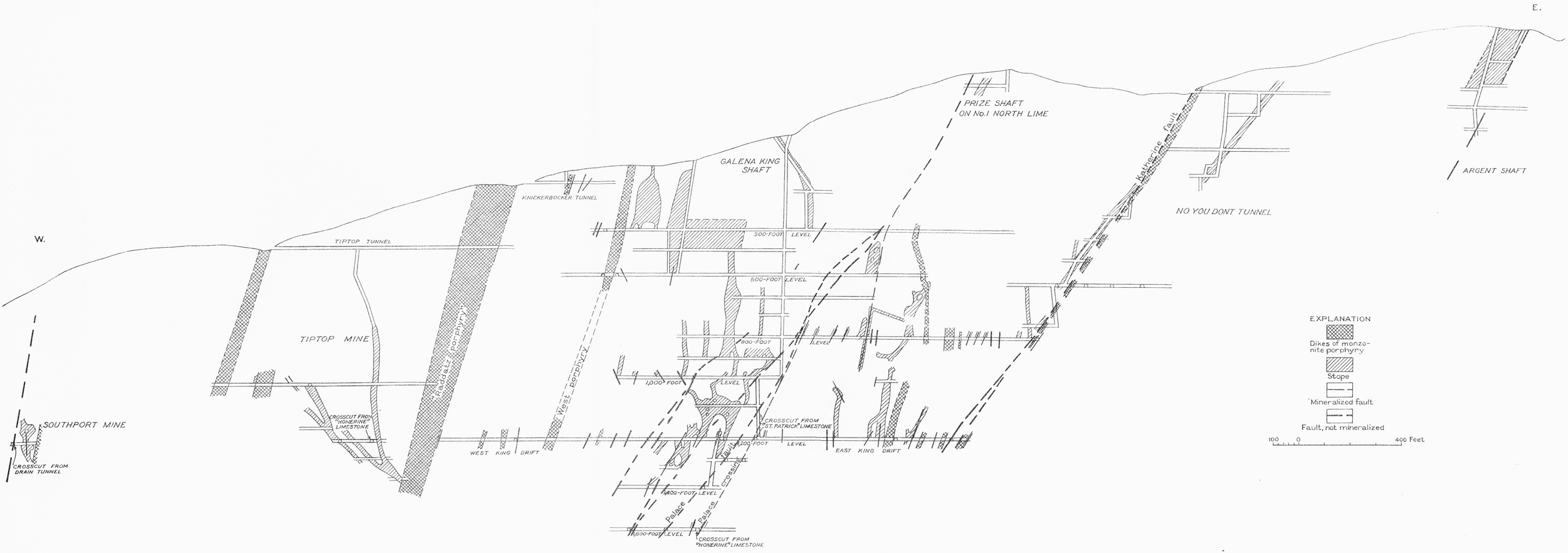


MAP SHOWING WORKINGS OF THE CLIFF, HIDDEN TREASURE, SACRAMENTO, AND CHICAGO MINES, OPHIR DISTI



CHICAGO MINES, OPHIR DISTRICT

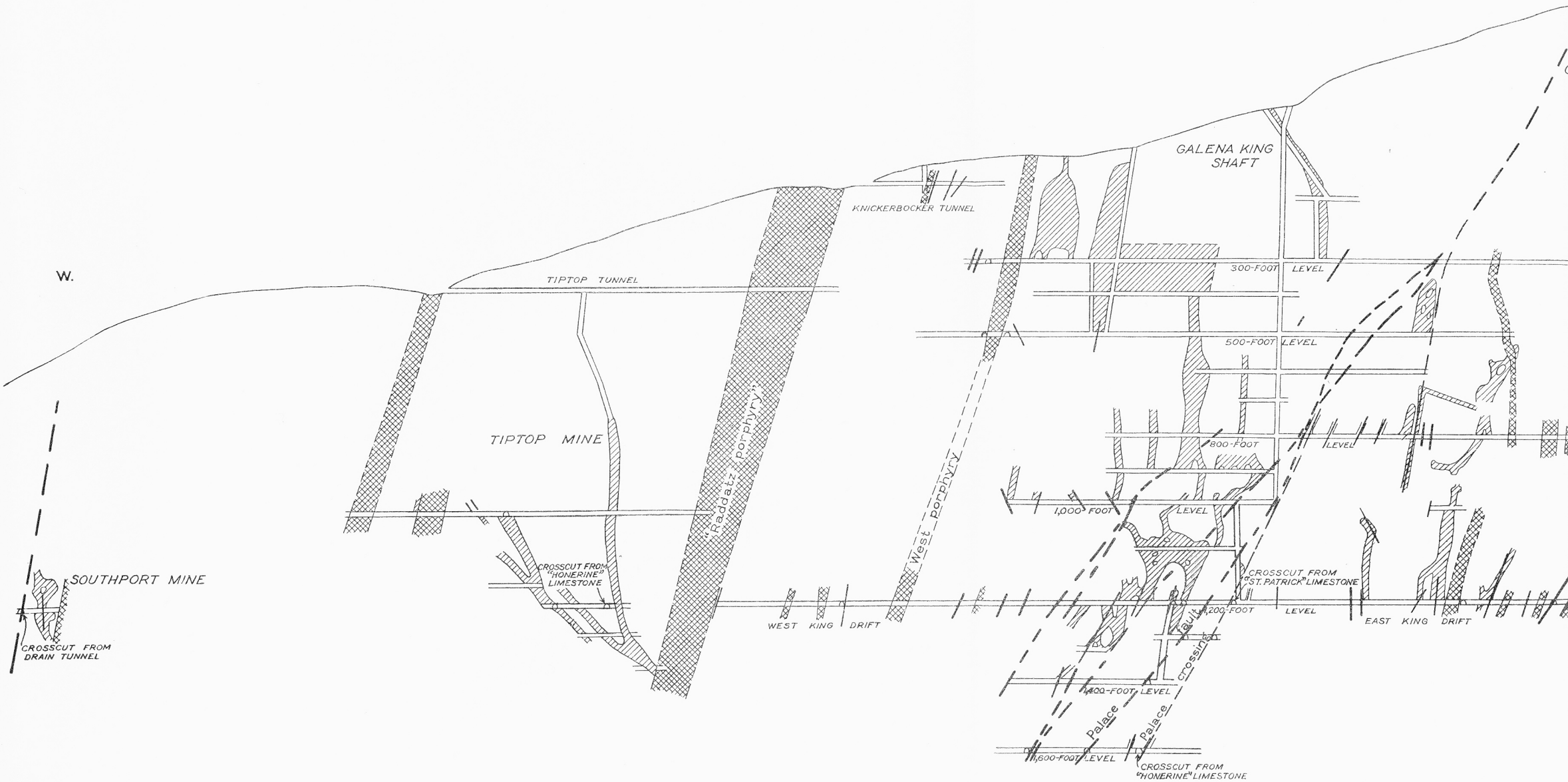

LOWER TUNNEL
Madison limestone
Jefferson (?) dolomite
INCLINE
RAISE
MIDDLE TUNNEL
DRIFT FROM
Steep stoped fissure
Fissure
Irregular stope
WINZE
Pine stump
El.8,459'
El.8,427'
El.8,386'
El.8,326'
PIPE LINE
El.8,315'
WATER TANK
El.8,401'
Big stopes
Small stopes
Fault
Jefferson (?) dolomite
Madison limestone
BIG STOPES
LOWER INCLINED SHAFT 500'
UPPER TUNNEL
El.8,151'
DEEP SHAFT
El. 8,665'
BULKHEAD
Stope (filled)
Air
El. 8,340'
Porphyry dike
SHAFT 40' DEEP
El. 8,481'
ORE SHOOT
Stoped up from lower tunnel
CLIFF TUNNELS
El.7,687'
100 0 500 Feet



EAST-WEST VERTICAL PROJECTION OF WORKINGS ON THE "GALENA KING" LIMESTONE, STOCKTON DISTRICT

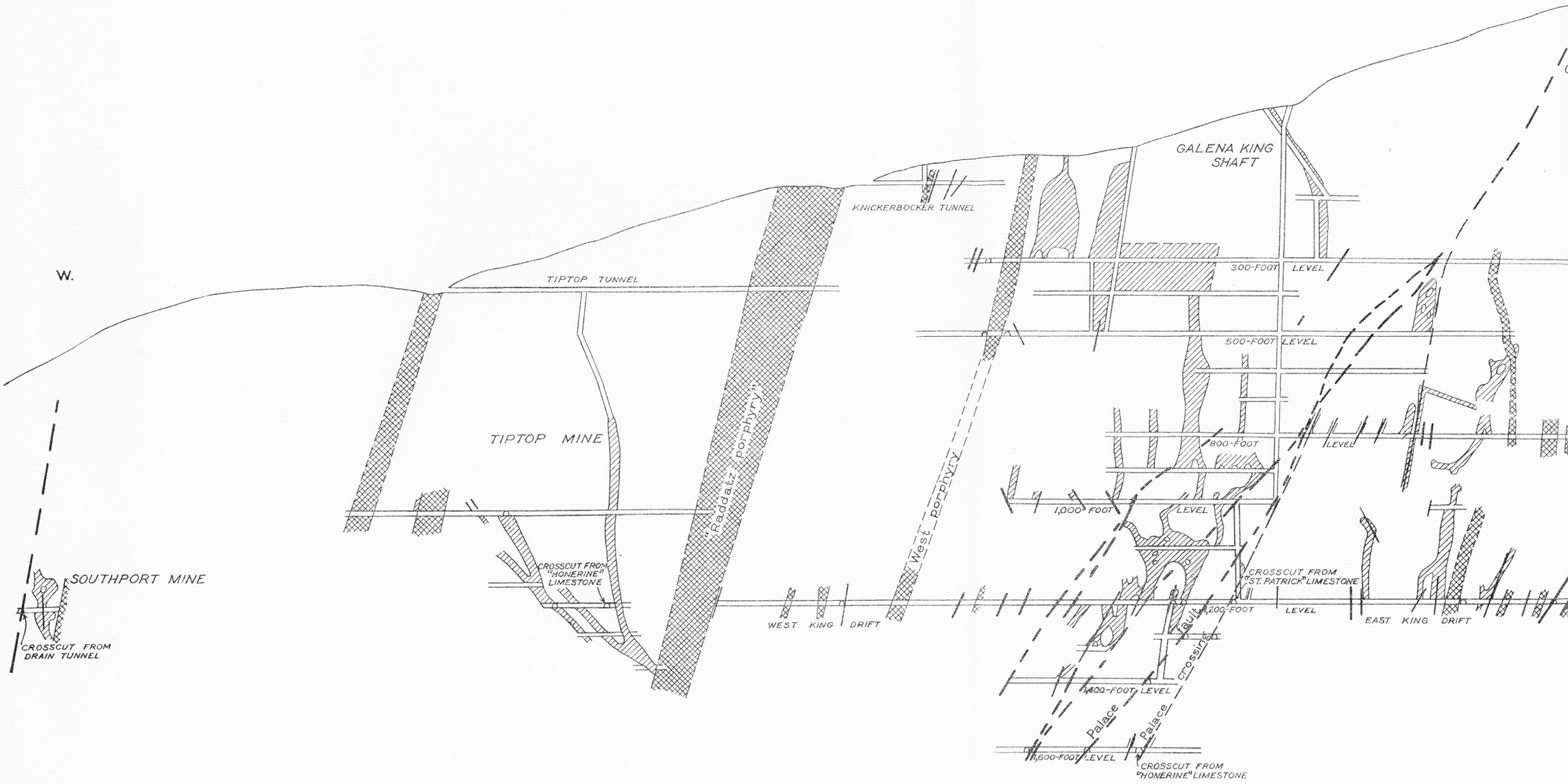
By S. E. Craig, geologist, Combined Metals Reduction Co.

EXPLANATION
Limestone
Quartzite
Monzonite porphyry
Shale
Breccia
Fault
Mineral fissure
Strike and dip
Geology shown on 300, 500, and 800 foot levels only
White quartzite
"Paisley" limestone
Black thin-bedded shale
No.2 north limestone
No.1 north limestone
No.1 south limestone
Nonmineral fissure
Vertical fault
JACOBSON'S TUNNEL
1080-FOOT LEVEL
1000-FOOT LEVEL
900-FOOT LEVEL
800-FOOT LEVEL
650-FOOT LEVEL
600-FOOT LEVEL
500-FOOT LEVEL
400-FOOT LEVEL
300-FOOT LEVEL
"45° fault" on 800-foot level
Mineral fissure
Water fault
Fissure
Galena King" limestone
Probably "Galena King" limestone
"45° fault" on 500-foot level
"45° fault" on 300-foot level
Drift on "Galena King" gouge
STOPE
OLD SHAFT
GALENA KING SHAFT
CAVED
NORTH CROSSCUT
SOUTH CROSSCUT
50 0 200 Feet



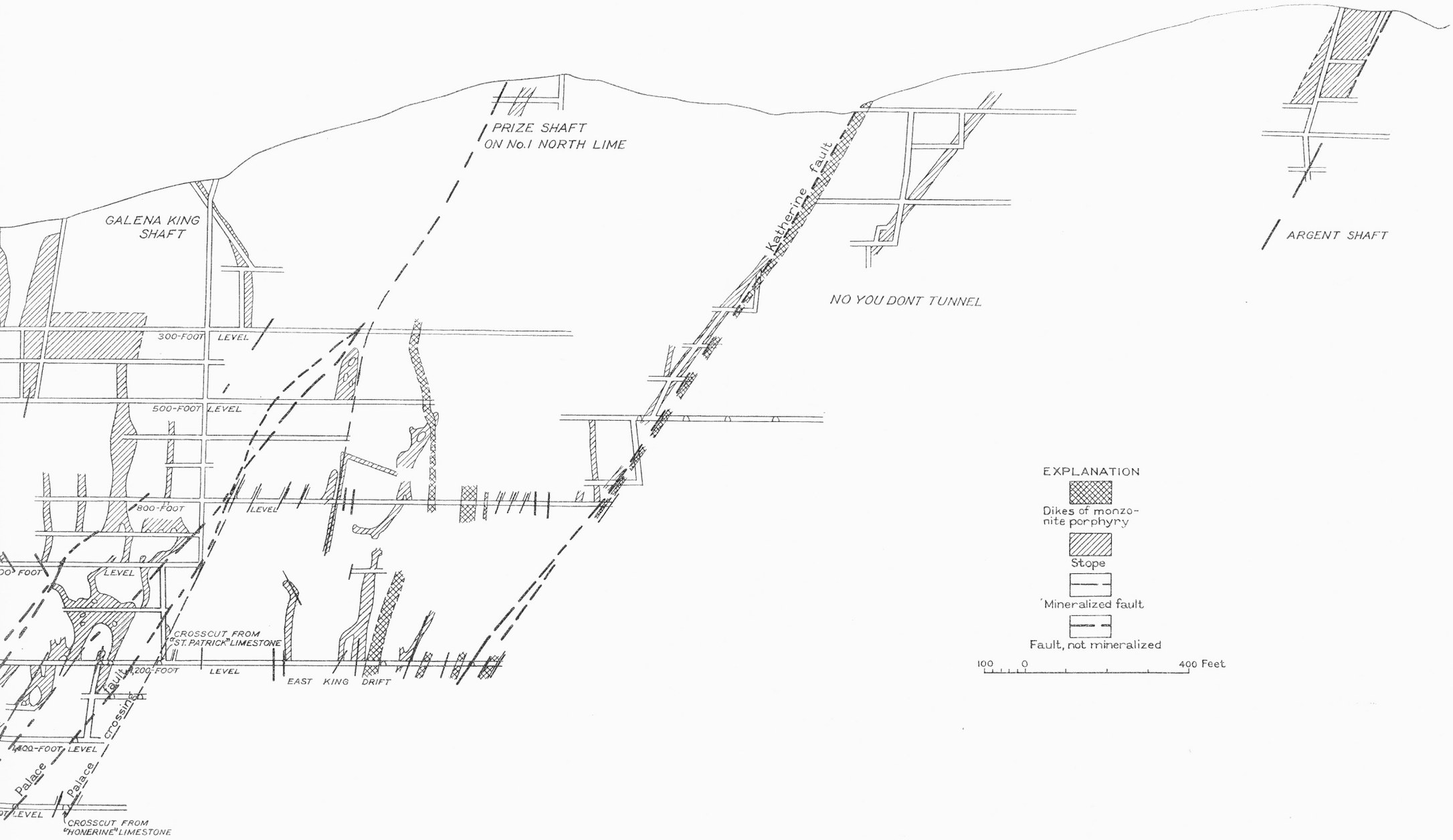
EAST-WEST VERTICAL PROJECTION OF WORKINGS ON THE "GALENA KING" LIMESTONE.

By S. E. Craig, geologist, Combined Metals Reduction Co.



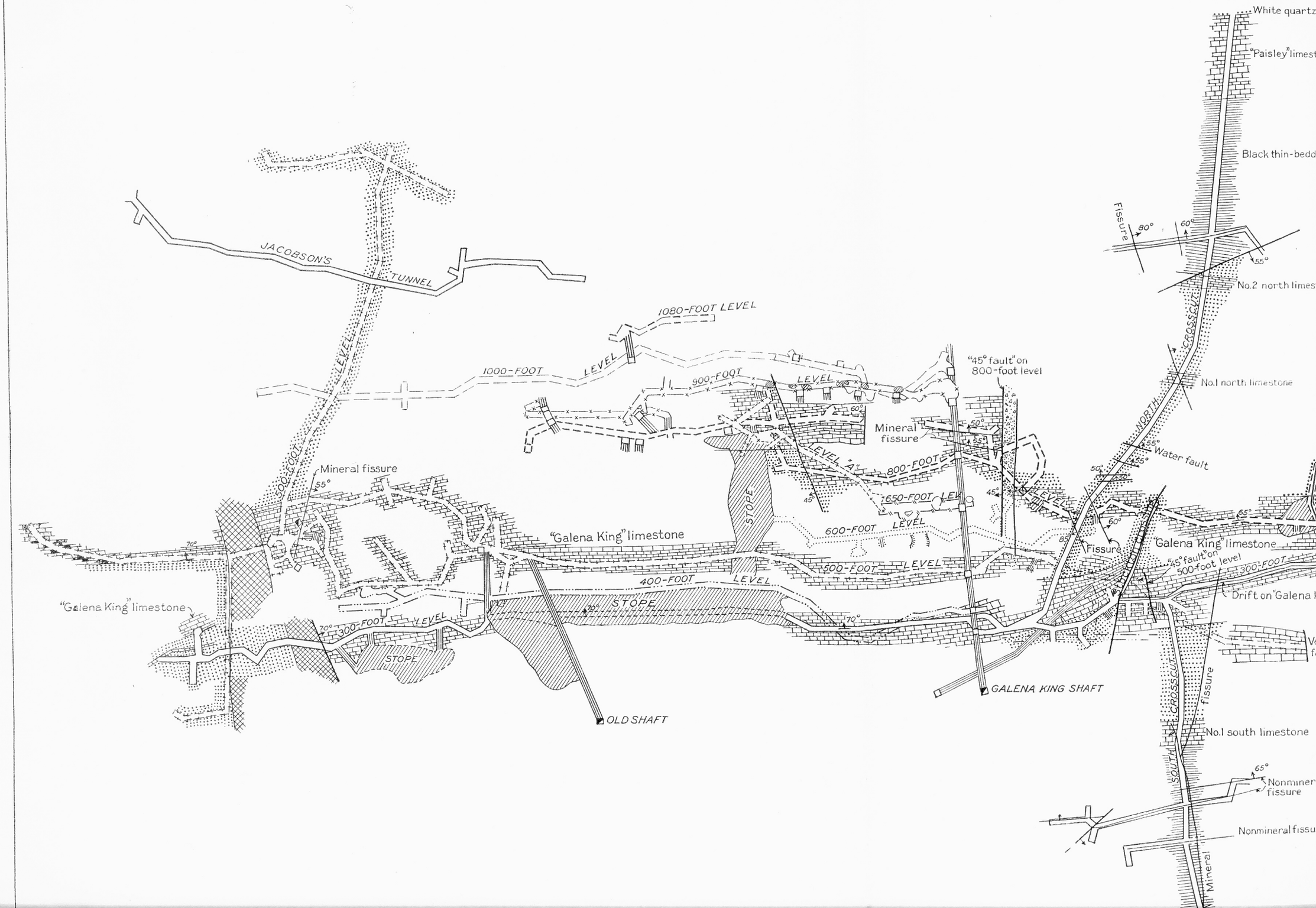
EAST-WEST VERTICAL PROJECTION OF WORKINGS ON THE "GALENA KING" LIMESTONE,

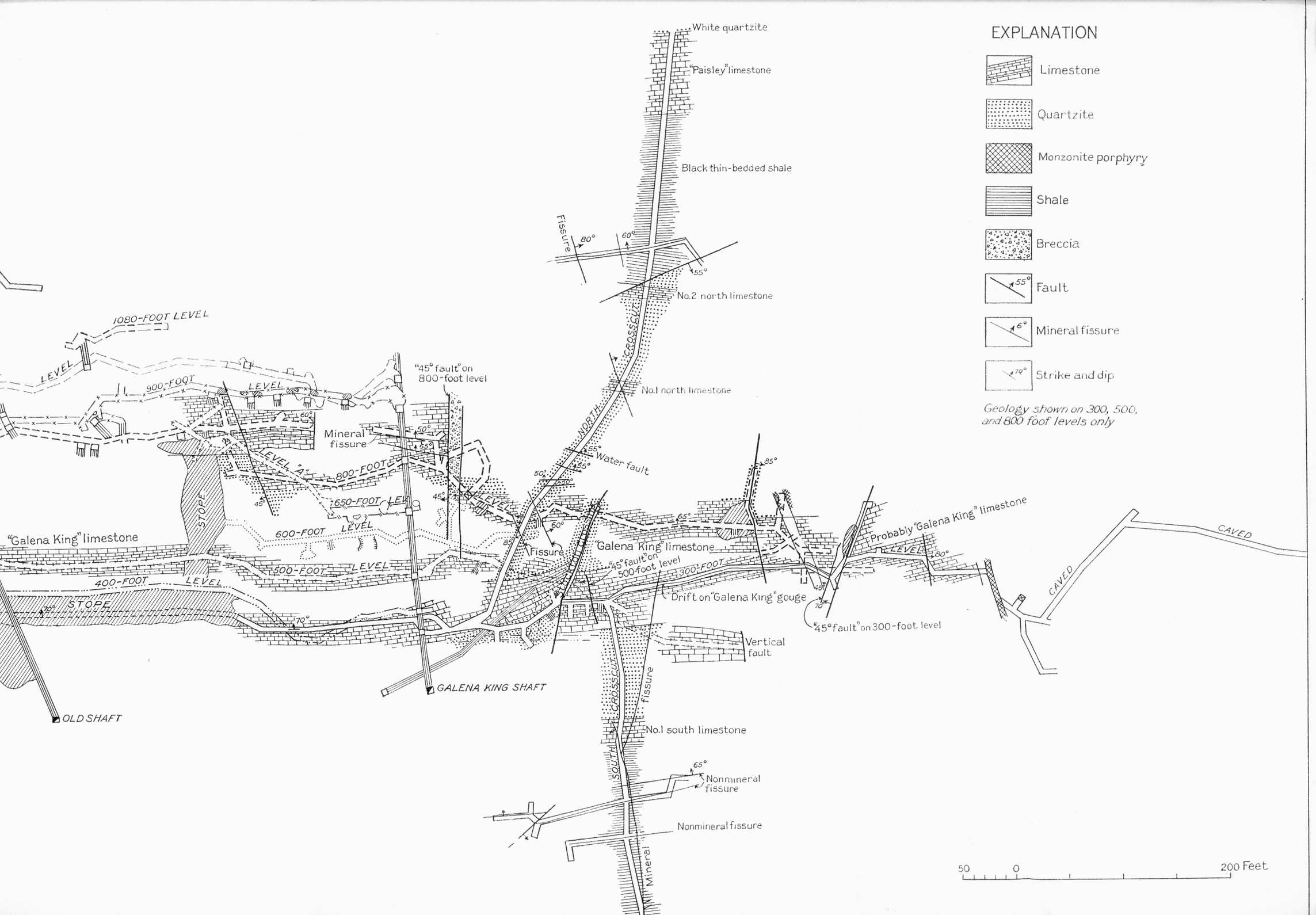
By S. E. Craig, geologist, Combined Metals Reduction Co.

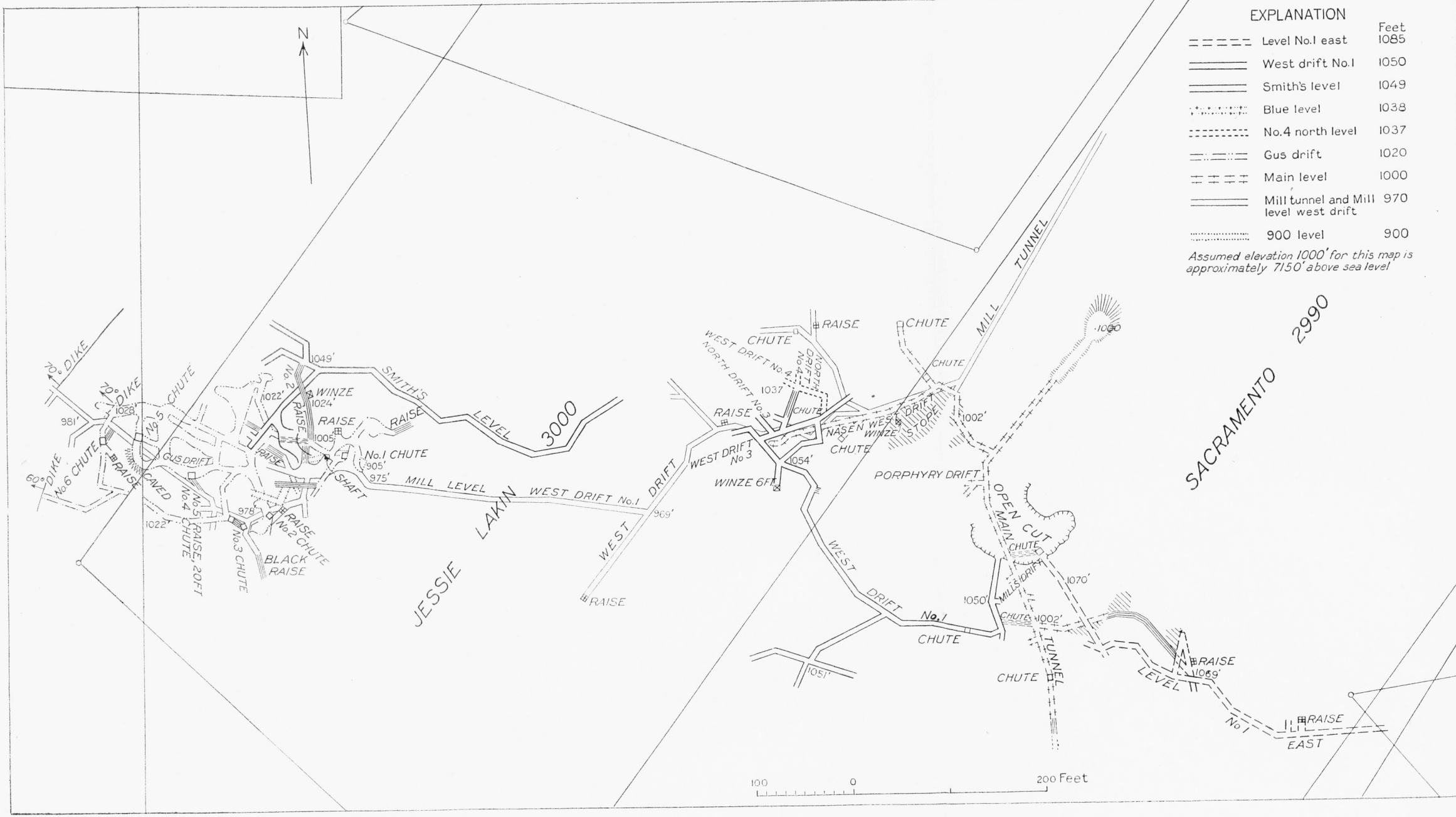


TION OF WORKINGS ON THE "GALENA KING" LIMESTONE, STOCKTON DISTRICT

By S. E. Craig, geologist, Combined Metals Reduction Co.


JACOBSON'S TUNNEL
1080-FOOT LEVEL
1000-FOOT LEVEL
900-FOOT LEVEL
800-FOOT LEVEL
700-FOOT LEVEL
650-FOOT LEVEL
600-FOOT LEVEL
500-FOOT LEVEL
400-FOOT LEVEL
300-FOOT LEVEL
"45° fault" on 800-foot level
Mineral fissure
"Galena King" limestone
STOPE
OLD SHAFT
GALENA KING SHAFT
Water fault
Fissure
"45° fault" on 500-foot level
Drift on "Galena
No.1 north limestone
No.2 north limes
No.1 south limestone
Nonmineral fissu
White quartz
"Paisley" limest
Black thin-bedd
Nonminer
fissure
Mineral


EXPLANATION
Limestone
Quartzite
Monzonite porphyry
Shale
Breccia
Fault
Mineral fissure
Strike and dip
Geology shown on 300, 500, and 800 foot levels only
White quartzite
"Paisley" limestone
Black thin-bedded shale
Fissure
No.2 north limestone
No.1 north limestone
CROSSCUT
NORTH
Water fault
1080-FOOT LEVEL
900-FOOT LEVEL
"45° fault" on 800-foot level
Mineral fissure
LEVEL "A"
800-FOOT LEVEL
650-FOOT LEVEL
600-FOOT LEVEL
500-FOOT LEVEL
400-FOOT LEVEL
STOPE
"Galena King" limestone
Fissure
Galena King" limestone
"45° fault" on 500-foot level
300-FOOT LEVEL
Drift on "Galena King" gouge
"45° fault" on 300-foot level
Probably "Galena King" limestone
CAVED
CAVED
Vertical fault
GALENA KING SHAFT
OLD SHAFT
SOUTH CROSSCUT
fissure
No.1 south limestone
Nonmineral fissure
Nonmineral fissure
Mineral
50 0 200 Feet



MAP OF THE WORKINGS OF THE SACRAMENTO MINE, MERCUR AREA